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THE EFFECTS OF CONFINEMENT AS A FACTOR IN [illegible] MANNED SPACE FLIGHT

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Prepared by
LOVELACE FOUNDATION FOR MEDICAL EDUCATION AND RESEARCH
Albuquerque, N. Mex.

for

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THE EFFECTS OF CONFINEMENT AS A FACTOR IN MANNED SPACE FLIGHT

By T. M. Fraser

Prepared under Contract No. NASr-115 by
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PREFACE

Environmental stresses manifesting themselves in man at the psychophysiological interface commonly involve problems of interest to the physiologist, psychologist, and environmental medical specialist alike, while guidelines to the solution of these problems are sought by the designers and operators of any vehicle in which the stress might be a feature. One such stress is that of confinement within a limited space.

Because of the engineering constraints imposed on weight and volume of spacecraft, and in particular on the free internal volume, it has become necessary to determine to what extent man can continue to function usefully within a very limited space. In this paper the nature of confinement stress is defined and an examination made of its psychophysiological effect on man.

However, while this paper is in part a critical review of the literature it is also an analysis of data from many sources which culminates in a definition of threshold tolerance curves, and recommendations concerning acceptable free volume requirements for varying durations of confinement.

In a departure from normal procedure, an annotated bibliography is appended instead of the usual reference list. Those few references where an abstract is not provided contain subject matter of no direct interest to the problems of confinement, and are included merely because of some pertinent comment found therein.

My thanks are due to Drs. A. H. Schwichtenberg, E. M. Roth, and D. E. Busby of the Department of Aerospace Medicine and Bioastronautics for their review and comments on this document, to Dr. C. W. Sargent and the staff of the Document Library for their assistance in obtaining the references quoted herein, and to my secretary Mrs. J. Whalon for her willing efforts.

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SUMMARY

After an initial introduction, the nature of confinement is discussed in relation to isolation and sensory deprivation. The operational and experimental experience of confinement is then tabulated in terms of conditions, subjects, available volume, and significant findings. The response of man to confinement is examined with respect to the psychological and the physiological effects. Excluding as much as possible the elements of sensory deprivation and isolation the psychological response is shown to be manifested in the form of subjective emotional reactions, discomfort and rarely, perceptual aberration. Performance decrement is relatively slight. The physiological response is seen to be one of non-specific reaction to stress accompanied by specific changes (e. g., cardiovascular deconditioning) attributable to the reduced mobility. There is a suggestion that some adaptation takes place with continued confinement, but that the adaptation breaks down after a total of about 60 days. Tolerance to confinement is discussed and tolerance curves are presented indicating a threshold of acceptable tolerance, a threshold of unacceptable tolerance, and an intermediate zone. The curves indicate that, for duration of 30 to 60 days confinement, about 150 cubic feet of free volume per man are necessary. Studies are needed to determine the requirements for more prolonged durations. Tolerance is modified by habitability, work, rest, recreation, and exercise schedules. The effects of weightlessness and the space environment on confinement durations of more than a few days are not known. Weightlessness may improve the restrictive aspects and hence improve tolerance, but at the same time aggravate, for example, the cardiovascular decrement. Recommendations for further studies are included.

Author

"But though my wing is closely bound
My heart's at liberty.
My prison walls cannot control
The flight, the freedom of the soul"

A Prisoner's Song. Jeanne Guyon, 1648-1717

THE EFFECTS OF CONFINEMENT AS A FACTOR IN MANNED SPACE FLIGHT

In the year 1756, at a time when Britain was extending dominance over India, the Nawab of Bengal, Suraj-ud-Dowlah, captured from the British the fortified city of Fort William. Although most of the European inhabitants escaped, some 146 men, women, and children, were confined by the troops of the Nawab in a guardroom measuring 18 ft. x 14 ft. 10 in. and ventilated by two small windows. The approximate maximum area per person was a little under two square feet. In the tropical heat and humidity, without food and water, and no doubt distressed by fear, only 23 survived after less than 24 hours confinement. The infamous Black Hole of Calcutta, as it became known, has gone down into history as a supreme example of the effects of confinement on man.

History, of course, is replete with tales of confinement, from the dungeons of medieval times and before, to the slave ships of the eighteen hundreds, or the political prison camp boxcars of more recent years. Even in recent times, however, some of the State and Federal jails have provided prime examples of studies in prolonged confinement. Bruce [8] (1963) describes the standard cell in Alcatraz, 5 ft. x 8 ft., with a barred front, concrete rear wall, and steel side walls, and notes that it contained a folding steel cot, a toilet without a seat or lid, and two steel folding shelves for use as seat and desk. In this, with work periods and "recreations," an occupant might spend most of a life time. In addition, for many years the element of social isolation was compounded by permitting conversation only during a three minute break each morning and afternoon. If conditions in the standard cell were severe, those in the punishment cells or "deep hole" were more so. Without light or special ventilation, without facilities of any kind other than a hole in the floor for toilet purposes, on a gruel diet, prisoners were maintained in the "hole" for 19 consecutive days before being removed for one day and then returned to complete their particular sentence. One prisoner had the dubious honor of serving 165 days in this manner. Warden Johnson in his memoirs stated, ". . . . we had to chain the men to keep them from breaking out and running amuck," while Bryan Conway, himself a prisoner, related later, "Men go slowly insane under the exquisite torture of routine."

Routine, however, along with perceptual and social isolation are only incidental to and not necessarily integral parts of confinement. What then is the nature of confinement?

THE NATURE OF CONFINEMENT

Some confusion still exists in the literature on the meaning, significance, and interrelationships of the different concepts associated with confinement. These include concepts of restraint, environmental limitations, sensory deprivation, solitude, perceptual isolation, social isolation, and other extremes, each or all of which may be combined to a greater or less degree to produce a stressful situation.

Sells and Berry[84] (1958), echoed by Chamber and Fried[15] (1963) consider that confinement refers to restraint or restriction of freedom of movement or action, by command, fear, physical enclosure, or encapsulation. They point out, however, that aloneness (solitude) and separation may be additional aggravating factors in a confinement situation. Confinement, however, does not necessarily imply isolation, although, as Ormiston[78] (1961) notes, it may include some limitation of sensory inputs. Most authors, e.g., Sells and Berry[84] (1958), Wheaton[98] (1959), Walters and Henning[92] (1961), Ormiston[78] (1961), and Chambers and Fried[15] (1963), agree that the essential nature of isolation lies in the separation of an individual from his normal social and physical environment. Again, however, isolation does not necessarily imply either confinement or sensory deprivation although it could have elements of both. Walters and Henning[92] (1961) point out with considerable justification that the effects of sensory deprivation and social isolation have been inextricably confounded. In point of fact, however, there is no such entity as sensory deprivation in the conscious individual. What is loosely known as sensory deprivation is in reality a reduction in the totality of stimulation in the environment, which may arise from a reduced sensory input, or a distorted sensory input.

Thus, fundamentally there are two basic and interrelated concepts, confinement and isolation. These may be further subdivided as shown below:

Confinement

a) Physical
   i) Restrictive
   ii) Determinative

b) Temporal
   i) Restrictive
   ii) Determinative

Isolation

a) Perceptual
   i) Sensory reduction
   ii) Sensory distortion

b) Social
   i) Solitude
      A. Single
      B. Group
   ii) Rejection
      A. Single
      B. Group

Confinement then may be physical, temporal, or both. Physical confinement may be restrictive, in that the subject is restrained by belts, harnesses, pressure suit, couch, encapsulation, etc., or it may be determinative, in that he is free to move within the confines of a cabin, space station, lunar or planetary refuge. This classification of course would also apply to those confined by order, fear, hostile terrestrial environment, etc.. Temporal confinement may be restrictive or determinative; restrictive, if the subject is confined by curfew or by the rigidity of a work schedule; determinative, if the duration of his confinement is determined by some independent variable such as the duration of a mission or scientific experiment.

Isolation, which may occur concomitant with confinement, may be perceptual, social, or both. Perceptual isolation, which involves essentially disturbances of perception, may arise from sensory reduction such as has been demonstrated in the McGill experiments (Bexton, et al. [6](1954), Heron, et al. [52](1956), Heron[51](1957)) and in naturally occurring situations such as the "break-off phenomenon" (Clark and Graybiel[18](1957)) or the peculiar Arctic disorder of "kayak-angst" described by Gussow[39](1963). Perceptual isolation may also be associated with sensory distortion,as in studies such as those of Zubek[102](1963) where subjects are exposed to non-patterned sensory stimulation.

Social isolation on the other hand involves the concepts of aloneness and

OPERATIONAL AND EXPERIMENTAL EXPERIENCE OF CONFINEMENT

As was noted in the introduction, history is rich in the tales of confinement, voluntary, and, more commonly, involuntary. Anecdotal reports, however, while descriptive for background purposes, are highly subjective and very unrewarding as factual sources. Consequently, it is necessary to turn to regulated and preferably controlled experimental studies, and detailed operational experience, to obtain necessary data. Although there are numerous ways of presenting the material it is convenient to group the various studies under the following headings:

- a) Simulator studies
  - i) Single man
  - ii) Multi-man
- b) Confined chamber studies
  - i) Single man
  - ii) Multi-man
- c) Cockpit studies
- d) Vehicle studies
- e) Submarine studies
- f) Spacecraft studies
- g) Other: Bed, respirator, immersion, etc.

The available data, including some derived from the review of Jones and Prince[60] (1964), are presented in Table 1. Most of the columns are self explanatory. The total free volume refers to the available volume within the experimental device or vehicle, and in some cases represents a calculation from inadequate data. For some instances, the free area is quoted in addition. The summarized findings represent the highlights of a quoted study as they have application to the problems of confinement and habitability.

In addition to the operational and experimental experience quoted in Table 1, numerous confinement studies have been carried out with a primary view to determine the effects of sensory reduction. These have been very separation from a normal environment. Thus it may encompass solitude in the presence of full normal sensory stimulation, either for the individual or the small group, or it may involve rejection of the individual by the group, or a small group by a larger group.

Rarely, if ever, do confinement and isolation exist as single entities. Isolation commonly accompanies confinement. Social isolation is a factor in perceptual isolation, just as solitude is a factor in determining the effects of sensory reduction. These in turn seem to be determined by a state of arousal of the individual which normally remains at a level of awareness commensurate with the demands of the environment. Thus the nature of the perceived environment serves to determine the interrelationship of the various factors involved.

Confinement then is but one factor, albeit a major one, in the environment under consideration, and as Walters and Henning [92] (1961) remark: "It would be hazardous to attempt, at our present state of knowledge, a theoretic integration that would serve equally well to explain current findings concerning sensory deprivation, the various conditions that have been labelled social isolation, and reactions to living in a small group." What to one investigator may be considered as a physiological response to stress may be dismissed as anxiety by another. The findings determined on the basis of neurophysiologic investigations can be in conflict with those based on psychoanalytic study, learning theory, or descriptive observation; and, in fact, many investigators have manipulated the environment without simulating any real life situation.

What then is confinement? For the purposes of this study it may be defined as a physical and temporal limitation on the activities and translational motions of an individual or group, occasioned by enclosure within a restricting barrier, and sometimes associated with elements of perceptual and social isolation.

thoroughly reviewed by Zuckerman[103] (1964) who notes three common methods of obtaining sensory reduction, all of which have in addition elements of perceptual and social isolation as well as confinement. The methods employed are largely suspension in water, confinement within a poliomyelitis respirator, and confinement in a sound-reduced room. Usually the techniques also include darkness or unpatterned light, minimal intercommunication, steady white noise or noise masking, or sometimes clothing designed to reduce tactile stimulation.

Dr. Milton Grodsky (personal communication) draws attention to the importance of methodological considerations in confinement studies, as in others, since the methodology to a large extent determines the reliability and validity of the data obtained. In analysis of confinement data in particular, methodological considerations assume importance, since in most studies from which information can be derived, the experiment or operational trial was not primarily conducted to determine the effects of confinement, although confinement might well have been the most significant environmental factor. In fact, studies conducted solely to investigate the effects of confinement are so rare that little definitive information can be obtained from them.

Thus, it must be remembered that the studies outlined in Table I, subsequently discussed, and utilized to develop tolerance curves and recommended optima and minima, are not necessarily comparable, except that all of them show some aspects of confinement. They utilize differing physical plants, differing environmental variables, differing numbers of subjects, subject selection systems, and types of subjects, and differing criteria of performance and physiological impairment. At the same time, with suitable classification and interpretation, the confinement variable can be isolated at least to some extent, and, of course, without an examination of confinement experience as it exists, very little data would be available.

TABLE I

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experi-ments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Simulator Single	SAM one-man chamber, O_2/N_2 380 mm Hg total pressure; controlled heat and ventilation; unrestrained, minimal movement; partial pressure suit; 4:4 work rest schedule.	1	7	47 cu. ft.	47 cu. ft.	7 days	No physiological adaptation. Loss of work proficiency in non-pilot subjects, with marked perceptual aberrations. Loss of physical conditioning.	Steinkamp, et al., 1959. Hawkins & Hauty, 1959. Gerathewohl, 1959. Hauty, 1960.
	SAM one-man chamber. Noise masking. Constant internal illumination.	1	4	47 cu. ft.	47 cu. ft.	$1\frac{1}{2}$ days	Emotional disturbance. Perceptual aberrations.	Flaherty, et al., 1960
	Vostok simulator. Ambient pressure; 20° temperature; 30 - 70% humidity; Pressure suit.	1	?	90 cu. ft.	90 cu. ft.	? 1 day	No apparent disturbance in motivated subjects.	Volynkin & Yuzdorsky, 1962.
Simulator Multi	Lockheed-Georgia crew system mock-up; work area, sleeping area, leisure area; adequate illumination; noise masking; minimum intercom; OPN-360.	5 6	1 1	1100 cu. ft.	250 cu. ft. 183 cu. ft.	15 days	Significant decrement in performance and psychological tests; decreased autonomic activation (i.e., increased skin resistance, decreased heart and respiration rate); Diurnal variation in performance and physiological status.	Adams & Chiles, 1961.

Continued on next page.

TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experi-ments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Simulator Multi (Cont)	Lockheed-Georgia; HOPE-II; 1 crew, 4:2 schedule; instructed to minimize diurnal effects.	6	1	1100 cu. ft.	187 cu. ft.	15 days	Declining performance. Irritability, sleepiness, fatigue Minor physical discomfort. Variations in performance related to motivation, diurnal cycling, duration of task.	Alluisi, et al., 1963.
	Lockheed-Georgia; HOPE-III, 2 crews, 4:4 schedule.	10	1	1100 cu. ft.	110 cu. ft.	30 days	Essentially no performance decrement except diurnal. Declining psychophysiological "activation". Some irritability and fatigue.	Alluisi, et al., 1963.
	Lockheed-Georgia; HOPE-IV, HOPE-V; 4:4 schedule with one 44 hour continuous work period.	10	1	1100 cu. ft.	110 cu. ft.	12 days	Similar to above; sleep loss resulted in additional performance decrements. Impact of sleep loss on tasks depends on position of tasks in the activity-passivity continuum.	Alluisi, et al., 1964.
	Lockheed-Georgia; HOPE-VI, HOPE-VII; 4:2 schedule with one 40 hour continuous work period.	6	1	1100 cu. ft.	187 cu. ft.	12 days		

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TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experiments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Simulator Multi (Cont)	North American Aviation; disc-like mock-up.	2	1	1600 cu. ft.	800 cu. ft. (200 sq. ft.)	4 days	No impairment	Celentano, et al., 1963.
	SAM 2-man chamber; simulated space missions, work scheduled on 22 hour day with 6 - 7 hours sleep; experiments conducted at 18,000 ft. equivalent; 40% O_2, 60% N_2, and also at 33,500 ft. 100% O_2.	2 2 2	1 2 1	212 cu. ft. 212 cu. ft. 212 cu. ft.	106 cu. ft. 106 cu. ft. 106 cu. ft.	14 days 30 days 17 days	Subject variation. Some irritability, resentment; mild illusions; performance generally maintained; loss of appetite, insomnia; loss of weight and fluid; some CVS deconditioning; increase in reaction time in 17 day flight.	Gerathewohl, 1959. McKenzie, et al., 1961. Morgan, et al., 1961. Welch, et al., 1961. Flinn, et al., 1961. Hauty, 1964. Cramer & Flinn, 1963. Hartman & Flinn, 1964.
	Republic; Converted altitude chamber, 30 ft. long by 13 ft. diameter; 100% O_2 environment at 3.8, 5.0, 7.4 psi; air environment at 14.7 psi.	6	4	1268 cu. ft.	211 cu. ft.	14 days	No deterioration of general mental, sensory, or motor performance. Aerotitis, substernal discomfort, coughing and eye irritation, probably attributable to O_2.	Helvey, et al., 1962.
	General Electric; 2 compartment simulator; cylindrical vertical shell, two 8 foot sections; 7 psi 50/50 O_2/N_2; Adequate light, temperature ventilation, humidity.	4	1	860 cu. ft. Approx.	215 cu. ft.	30 days	Little decrement in psychol. testing and task performance. Loss of "group cohesiveness". Minor medical problems.	General Electric, 1964.

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TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experi-ments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Simulator Multi (Cont)	Russian simulated mission; with and without pressure suit; controlled variation in ionizing radiation, temperature, noise, CO_2, CO and contaminants.	1	?	?	?	10-120 days	Initial psychophysiological adaptation over 10 - 15 days followed by establishment of new level with normalizing of e.g., sleep, motor reaction, light sensitivity, performance error. Development of "asthenization".	Lebedinskiiy, et al., 1964.
	Martin Baltimore Lunar Mission simulation with lunar "bug"; flight deck, sleeping area, off duty area, maintenance area, galley; 26 hour duty cycle on major flight with two 4 hour sleep periods; pre-flight and inflight physical conditioning.	3 3	2 1	400 cu. ft. 400 cu. ft.	133 cu. ft. 133 cu. ft.	75 hours 7 days	Pilot studies No impaired performance, no fatigue; no evidence of adaptation; no alteration in time estimation; no major physiological change other than diurnal; no loss of CVS conditioning; slight loss of weight, some loss of creativity; mild irritability.	Grodsky & Bryant, 1962. Mallick & Ream, 1963. Hatch, et al., 1964
	Douglas orbiting vehicle simulator; 50/50 O_2/N_2; partially closed environmental system.	4	1	1000 cu. ft.	250 cu. ft.	30 days	No decrement in performance; no significant physiological changes;	Havens, D. E., 1965.
	NASA Ames conical capsule; no attempt to provide closed ecological system, atmospheric, or environmental condition; lunar mission simulation.	2	1	123 cu. ft.	61.5 cu. ft	7 days	Decrements in performance related to task complexity. Also improvements in some performance. Physiological deterioration similar to one week's bed rest including loss of Ca.	Rathert, et al., 1964. Patton, R. M., 1962.

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TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experi-ments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Simulator Multi (Cont)	Navy ACEL converted pressure chamber; work compartment, leisure compartment; 10,000 ft. equivalent, O_2 55%, N_2 45%; average temperature. 65 - 75° F; relative humidity 70%.	6	1	450 cu. ft.	75 cu. ft.	7 days	Discomfort, complaint of odor, food monotony, humidity. No deterioration of intellectual function. Performance variability, perhaps from boredom and diurnal cycling. Decrease in physiological "activation" except in emergency. Weight loss.	Hendler & Mancinelli, 1958. Gell, 1958 Hanna & Gaito, 1960. Hanna, 1962.
	Navy ACEL; closed-loop solid chemical rebreathing system.	6	1	450 cu. ft.	75 cu. ft.	8 days	Performance of routine tasks deteriorated rapidly; time estimation disturbed; tasks involving reasoning appear to depend on "consensual validation"; alterations in catecholamine excretion.	Burns, 1959. Burns & Gifford, 1961. Tiller & Figur, 1959.
	North American Aviation; conical shaped mock-up; simulated space mission; ventilation by mesh screen wall; work space and sleeping space; work schedules 2:2 with 6 hours sleep.	3	1	200 cu. ft.	67 cu. ft. (13 sq. ft.)	7 days	Reduced metabolic rate; weight and fluid loss; reduced physical activation; fatigue, sleepiness.	Celentano, et al., 1962.
	North American Aviation; cylindrical mock-up; simulated space mission.	4	1	1500 cu. ft.	375 cu. ft. (37 sq. ft.)	7 days	Some reduction in metabolism and physiological activity.	Celentano, et al., 1963.

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TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experi-ments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Simulators Multi (Cont)	WADC long range mission simulator; interior designed to minimize discomfort and monotony; simulated SAC mission; ambient environment.	5	3	700 cu. ft. Approx.	140 cu. ft.	5 days	Initial psychological set maintained; trend towards regressive behavior; individual and diurnal variations in physiological findings; dehydration.	Ruff, et al., 1959.
Confined Chambers Single	Navy isolation chamber; acoustically insulated; darkness; intercom for test purposes; Mercury type couch.	1	6	192 cu. ft.	192 cu. ft.	4-24 hrs.	Alteration in response to psychological testing related primarily to personality and environment, and less to duration. Reduction in physiological activation to lower level.	Hanna, et al., 1963.
	"Coffin-like" chamber; ambient room environment; some degree of perceptual isolation; out of chamber for hygienic purposes.	1	22	28 cu. ft. Approx.	28 cu. ft. Approx.	7 days.	Impaired intellectual performance; significant EEG change; deteriorated physical condition.	Zubek & Wilgosh, 1963.
	HUMRRO light proof and sound proof cubicle; very limited floor space; air conditioned; darkness; intercom available, no smoking.	1	8	360 cu. ft. Approx.	360 cu. ft.	96 hrs.	Restlessness, fearfulness, unpleasant thoughts, boredom; inefficient thought processes, reduced reasoning ability, visual hallucinations.	Myers, et al., 1962.

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TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experiments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Confined Chamber Single (Cont)	WADD windowless cubicle; aircraft seat and table; sound masked; lit.	1	35	260 cu. ft.	260 cu. ft.	8 hrs.	Changes in response to presentation of visual illusions; no significant changes in tracking or monitoring; somatic complaints.	Ormiston, 1961
	WADD sound proof room; bed, refrigerator, toilet, experimental condition variable from darkness and silence to unpatterned light and noise	1	100+	450 cu. ft. 65 sq. ft.	450 cu. ft. 65 sq. ft.	3 hrs - 7 days	Initial panic; reorganization; anxiety; disorganization; effects depend on circumstances surrounding isolation, subjective personal factors, sensory input, nature of confinement, communication, aloneness, duration, knowledge and control of duration, activities.	Ruff, et al., 1959.
	Russian closed chamber; solitude, lack of two-way communication; near isolation from light, sound, and other stimulation; otherwise ambient environment; work scheduling.	1	?	?	?	10-15 days	EEG changes; increased latency of EMG response; decrease in "level of prescribed (psychological) activity", most marked in second half of test and associated with decrease in ketosteroid excretion.	Gorbov, et al., 1964.

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TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experiments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Confined Chamber Single (Cont)	U. of Maryland programmed environment - 3 rooms air conditioned, sound attenuated and lit as program demanded; all activities, including eating sleeping, etc., determined by following pre-arranged automatic plans; minimum 2-way communication.	1	1	1368 cu. ft. total volume; 171 sq. ft. total area; limited area available at one time.	1368 cu. ft. total volume; 171 sq. ft. total area; limited area available at one time.	152 days	Progressive behavioral decrement; increasing negative and somatic complaints; increasing sleep; decreasing creative activity; decreasing co-operation.	Findley, et al., 1963.
Confined Chamber Multi	Lockheed Georgia; flight station mock-up distributed within a laboratory; left mock-up for meals.	8	2	1000 cu. ft. Approx.	125 cu. ft.	4 days	Relatively mild stress; no performance decrement; some resentment.	Adams and Chiles, 1960.
	U. of Georgia simulated fall out shelter; pilot study 1; bunk, recreational facilities, wash water, coffee, food ad lib; flush toilet; age range 8 - 63; mixed sexes; optimal ventilation, temperature and humidity.	10	1	650 cu. ft. 100 sq. ft.	65 cu. ft. 10 sq. ft.	3 days	Discomfort from sleep conditions, lack of space and exercise; loss of weight; no changes in psychological test results.	Georgia, U. of., 1963.

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TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experi-ments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Confined Chamber Multi (Cont)	U. of Georgia fall out shelter; pilot study 2; reduced diet; no wash water, coffee or cigarettes; otherwise as above.	10	1	650 cu. ft. 100 sq. ft.	65 cu. ft. 10 sq. ft.	3 days	Similar to above except greater weight loss.	Georgia, U. of., 1963.
	U. of Georgia fall out shelter; pilot study 3; high temperature (81^{o} F, E.T.) high humidity, low ventilation; very reduced diet (370 Kcal); chemical toilet; no bunks, blankets, recreation materials, wash water, coffee, cigarettes; age range 14 - 42 mixed sexes.	10	1	520 cu. ft. 80 sq. ft.	52 cu. ft. 8 sq. ft.	3 days	Considerable discomfort from sleep conditions and heat; manifestations of heat stress; lethargy and drowsiness; loss of weight.	Georgia, U. of., 1963.
	U. of Georgia fall out shelter; major study 1; temperature and humidity optimal; 300 Kcal per person; chemical toilets; no bunks; blankets, recreational material, wash water, coffee, cigarettes; mixed sex; age 15-50.	30	1	1560 cu. ft.	52 cu. ft.	4 days	8 occupants defected; consistent loss of physical fitness loss of weight; no significant depreciation in psychological test results; some depression; anxiety; considerable discomfort and decreased activity; some medical complaints.	Georgia, U. of., 1963.

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TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experi- ments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Confined Chamber Multi (Cont)	U. of Georgia fall out shelter; major study 2; conditions similar to study 1 with minor variations; age 9 - 67.	30	1	1560 cu. ft. 240 sq. ft.	52 cu. ft. 8 sq. ft.	14 days	5 occupants defected; weight loss; complaints of odors, sleep conditions, temperature, headache, anusea, fatigue.	Georgia, U. of., 1963.
	U. of Georgia fall out shelter; major study 3; similar to study 1 with minor variations in environment and facilities.	30	1	1560 cu. ft. 240 sq. ft.	52 cu. ft. 8 sq. ft.	14 days	2 occupants defected; weight loss; complaints re sleep conditions, odors, toilet, temperature; headaches, nausea, colds.	Georgia, U. of, 1963.
	U. of Georgia fall out shelter, major study 4; temperature and humidity optimal; food 900 Kcal; no bunks, blankets, recreation material, wash water; subjects children and 2 adults.	28 children 2 adults	1	1170 cu. ft. 180 sq. ft.	39 cu. ft. 6 sq. ft.	7 days	11 children and shelter manager defected; loss of weight; no loss in grip strength or endurance; loss in leg strength; no significant changes in psychomotor tests; no significant changes in psychological tests, discomfort for food, toilet, sleeping, and absence of method to tell time.	Georgia, U. of., 1963.

Continued on next page.

TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experiments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Confined Chamber Multi (Cont)	USNRDL shelter, arched roof; bunks erected for sleeping purposes; tables and benches for recreation and dining; state prisoner subjects; minimal sanitary facilities; 2000 Kcal diet; no bathing or shaving.	100	1	11700 cu.ft. 1200 sq.ft.	117 cu. ft. 12 sq. ft.	2 weeks	No defectors; discomforts related to restricted water, space, seating, noise, diet, boredom, etc; loss of weight, fatigue and listlessness; few medical complaints, notably constipation and skin disorders.	Strope, et al., 1960.
	USNRDL shelter; conditions similar to previous study with improved physical facilities.	100	1	11700 cu.ft 1200 sq.ft	117 cu. ft. 12 sq. ft.	5 days	Similar findings to previous study with lower standards of behavior attributed to deliberate passive role of commander.	Strope, et al., 1961.
Cockpit Studies	F-84 cockpit; noise masking 115 db.	1	4	<30 cu. ft.	<30 cu. ft.	56 hrs.	Variable loss in alertness to monitoring and clock-testing; progressive decrease in GSR; temporary hearing loss.	Chiles, 1955. Dempsey, et al., 1960.
	WADD escape capsule containing tasks, intercom, windows, water and fluids, relief tube. 4 groups: two confined on experimental diets, two unconfined: work scheduling; $8\frac{1}{2}$ hours sleep each night.	1	10 confined	27.5 cu. ft	27.5 cu. ft.	48 hrs.	No significant differences in performance or intellectual functioning; increased irritability; feeling of oppression.	Ormiston & Finkelstein, 1961.

Continued on next page.

TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experiments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Vehicle Studies	Armored personnel carrier M59; continuous motion of vehicle.	10	5	300 cu. ft.	30 cu. ft.	4 hrs.	Slight loss of equilibrium, loss of gross motor coordination; loss of firing accuracy; minimal discomfort.	Hicks, 1960 (a)
	Armored personnel carrier M113; continuous motion.	12	4	280 cu. ft.	23. 3 cu. ft.	8 hrs.	Loss in stamina, gross motor coordination, equilibrium, grenade throwing accuracy; cramping, nausea (30%), claustrophobia.	Hicks, 1960 (b).
	Armored personnel carrier M113; vehicle stationary; engine off for first 5 hrs.; environmental conditions severe.	10	4	280 cu. ft.	28 cu. ft.	12 hrs.	Significant loss of stamina, locomotor coordination, grenade throwing ability.	Hicks, 1961 (a)
	Armored personnel carrier M113; continuous motion; severe environmental conditions.	11	4	280 cu. ft.	25. 5 cu. ft.	24 hrs.	23 subjects defected. Study incomplete.	Hicks, 1961 (b)

Continued on next page.

TABLE I(Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experi-ments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Vehicle Studies (Cont)	Armored personnel carrier M113; continuous motion; environmental conditions extreme (fumes, equipment, cold, consensed water)	11	4	280 cu. ft.	25. 5 cu. ft.	24 hrs.	Defection prevented by impressed discipline; marked impairment in stamina, motor coordination, equilibrium, marksmanship; decrement in eye-hand coordination.	Hicks, 1962.
Submarine Studies	Submarine Nautilus, 1956; submerged and cruising; slightly elevated CO_2.	36	1	57000 cu.ft	1600 cu. ft	11 days	Minor psychophysiological changes increasing towards end of cruise.	Weybrew, 1957.
	Submarine Seawolf 1957; submerged; good environmental condition.	100	1	57000 cu. ft	570 cu. ft.	60 days	Loss of ability to concentrate; rise in muscle tension; insomnia; increase in heart rate.	Weybrew, 1961.
	Submarine Nautilus, 1958; submerged under ice-cap; good environmental conditions.	100	1	57000 cu. ft	570 cu. ft.	96 hrs.	High morale; no apparent problems.	Kinsey, 1959.
	Submarine Triton, 1960: submerged around world.	100	1	57000 cu.ft	570 cu. ft.	83 days	Some complaint of discomfort; headaches; reduced alertness; some decline in performance; irritability.	Weybrew, 1963.

Continued on next page.

TABLE I (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of Experiments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Chair rest	SAM; overstuffed chair tilted back; restrained except for hygiene; 8 hours bed rest; normal diet.	1	6	<25 cu. ft.	<25 cu. ft.	4 days	Cardiovascular deconditioning measured by tilt table; increased in weight; minimal hemoconcentration.	Lamb, Johnson, Stevens, 1964.
Bed rest	Lankenau Hospital; continuous bed rest, on pillow; no sitting; daily activities.	1	4	<25 cu. ft. estimated	<25 cu. ft. estimated	45 days	Cardiovascular deconditioning; inability to maintain upright position.	Birkhead, et al., 1963.
	SAM; bed rest studies; continuous, no sitting; normal diet.	1	12	<25 cu. ft. estimated	<25 cu. ft. estimated	4 wks.	Loss of plasma and total blood volume; cardiovascular deconditioning as measured by tilt table; loss of weight.	Miller, Johnson, Lamb, 1964.
	SAM; Bed rest studies with and without prophylactic measures; continuous during experimental periods; no sitting, 2400 Kcal diet.	1	72	<25 cu. ft. estimated	<25 cu. ft. estimated	2 wks.	Cardiovascular deconditiong; loss of plasma volume; loss of weight.	Miller, Hartman, Johnson, & Lamb, 1964.

Continued on next page.

TABLE 1 (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of Subject per run	No. of Experiments	Total free Volume or Area	Volume or area per man	Duration	Findings	Reference
Spacecraft	Mercury (MA-6); Adequate environmental control system; severe acceleration, buffeting, weightlessness.	1	1	47 cu. ft.	47 cu. ft.	Prelaunch: $3\frac{1}{2}$ hrs. Orbit: $4\frac{1}{2}$ hrs. Recovery: 1/3 hr.	Mild dehydration; slight weight loss; "stomach awareness"; minor discomfort.	NASA. 1962 (a)
	Mercury(MA-7); Adequate environmental control system; severe acceleration, buffeting, weightlessness.	1	1	47 cu. ft.	47 cu. ft.	Prelaunch: 3 hrs. Orbit: $4\frac{1}{2}$ hrs. Recovery: 2/3 hrs.	Fatigue; slight weight loss moderate diuresis.	NASA, 1962 (b)
	Mercury(MA-8); Adequate environmental control system; severe acceleration, buffeting, weightlessness.	1	1	47 cu. ft.	47 cu. ft.	Prelaunch: $2\frac{1}{2}$ hrs. Orbit: 9 hrs. Recovery: 2/3 hrs.	Orthostatic hypotension post flight; lability in heart rate; weight loss; mild dehydration; engorgement of leg veins; discomfort	NASA, 1963
	Mercury(MA-9) ; Occasional excessive heat; severe acceleration, buffeting; weightlessness; high humidity.	1	1	47 cu. ft.	47 cu. ft.	Prelaunch: $2\frac{1}{2}$ hrs. Orbit: 34 hrs. Recovery: 1/3 hr.	Orthostatic hypotension post-flight; moderate dehydration; change in white cell distribution; bilateral conjunctivitis, weight loss, discomfort.	NASA, 1963.
	Vostok I, II; Occasional excessive heat (87° F); severe acceleration, buffeting; ? rotation; weightlessness.	1	1	90 cu. ft.	90 cu. ft.	>1 3/4 hrs. >25 hrs.	Vestibular problems on Vostok II, fatigue; loss of weight; dehydration; change in tendon reflexes post-flight; EEG changes.	Volynkin, Yazdovskiy, 1962.

TABLE 1 (Continued)

EXPERIMENTAL AND OPERATIONAL EXPERIENCE

Type of Study	Operational Conditions	No. of subjects per run	No. of experiments	Total free volume or area	Volume or area per man	Duration	Findings	Reference
Spacecraft	**Gemini III: 5 psia O_2 atmosphere; acceleration, buffeting, weightlessness; some heat discomfort**	2	1	80 cu. ft. (approx)	40 cu. ft. (approx)	4 hours 52 min.	Nil of significance	NASA, 1966 (Gemini Mid-Program Conference Proceedings, Part 1 & 2 MSC, Houston, Texas, 1966
	Gemini IV; Same as III with EVA for one pilot at 3.5 psia.	2	1	80 cu. ft. (approx)	40 cu. ft. (approx)	96 hours 56 min.	Heart rate tends to rise initially, stabilizes in 36-48 hours, rises again 2-3 orbits before retrofire. B. P. follows heart rate. Diurnal cycles retained. Sleep duration reduced; sleep difficulty most marked in G IV. Cramp and fatigue of limbs; general fatigue most marked in G IV. Some dehydration in all, most marked in G IV. Irritability towards end of G VII. Weight loss in G IV, V, VII, averaging 7-8 lbs., largely replaced within 12 hours post-flight. "Heaviness" for several hours, and stiffness for several days post-flight. WBC increased (post-flight examination), returned to normal within 24 hours. RBC mass decreased 4-20%. Blood volume decreased 7-15% in G V & G VI; no decrease in G VII. Loss of Ca observed by bone densitometry in G IV, V, VII, least in G VII. Tilt table tolerance abnormal for 48-50 hours post-flight. 20% decrease in work tolerance in G VII.	
	Gemini V: Same general conditions; some high roll rates; target vehicle for rendezvous; pilot wore thigh cuffs for 4 days.	2	1	80 cu. ft. (approx)	40 cu. ft. (approx)	190 hours 56 min.		
	Gemini VI-A: Same general conditions; rendezvous maneuvers.	2	1	80 cu. ft. (approx)	40 cu. ft. (approx)	25 hours 51 min.		
	Gemini VII; Same general conditions; light weight suits, removed for part of time; occasional high tumble rates; in-flight regular exercise; pilot wore thigh cuffs entire time.	2	1	80 cu. ft. (approx)	40 cu. ft. (approx)	330 hours 35 min.		

THE RESPONSE TO CONFINEMENT

In the past, and in particular in the early studies of confinement, much emphasis was placed on the occurrence of perceptual disorders, bizarre behavior, and anxiety provoking stress. Many fears were expressed about man's ability to maintain rational and coherent control over himself and his environment; and, indeed, some of the earlier work by the McGill group (Heron [51] 1957) and at the School of Aviation Medicine (Steinkamp et al [88] 1959) tended to confirm this, until it was ralized that the perceptual aberrations and behavior disorders were primarily associated not with the confinement per se but with the accompanying perceptual isolation.

Nevertheless, it is advantageous to consider, at least briefly, the response to so-called "sensory deprivation." Solomon et al. [87] (1957) after reviewing much of the relevant literature, described the response in this manner: "Sensory deprivation has been produced experimentally by reducing the absolute intensity of stimuli, by reducing the patterning of stimuli, and by imposing a structuring of stimuli. Explorers have experienced it voluntarily and prisoners have had it thrust upon them.

"While there are many separate factors operating in these various situations, it is clear that the stability of man's mental state is dependent upon adequate perceptual contact with the outside world. Observations have shown the following common features in cases of sensory deprivation: the intense desire for extrinsic sensory stimuli and bodily motion, increased suggestibility, impairment of organized thinking, oppression and depression, and in extreme cases, hallucinations, delusions, and confusion."

These common features, however, do not occur in a completely random fashion. Ruff and his colleagues [83] (1959), in studies which involved maintaining a subject in a soundproof room containing a bed, refrigerator, and toilet, found, after analyzing more than 100 separate exposures, that a characteristic behavior pattern could be identified. With the onset of exposure a brief period of anxiety arises which, in a few subjects, may proceed to actual panic. This, however, usually subsides as the body defense mechanisms become effective.

In the second phase, the response varies according to the psychological needs of the subject. An obsessive compulsive individual may develop repetitive patterns of thought or activity while the passive-aggressive may consider the experience as a form of contest in which he must defeat the investigator. If the duration is sufficient, and here there is individual variation, a third phase is reached where anxiety is again manifested and thoughts tend to become disorganized. As unconscious material threatens to surface, the defenses become more primitive and the subject may manufacture irrational excuses to terminate the experiment or may actually quit with no expressed reason.

These situations, however, have only an associative relationship with the confinement experienced in the space cabin. There is no doubt, as Hall[40] (1963) asserts, that alone in a space cabin the occupant is deprived of companionship, exchange of thoughts, exercise facilities, and outlets for relaxation. He may be socially isolated, although on the larger missions even that will not apply, but he is far from being in a state of sensory deprivation. The comments of the astronauts and cosmonauts have attested to the wealth of sensation, visual, and otherwise, with which they are assailed, and even weightlessness, as a negative sensation, no doubt assists in contributing to the total perception.

To separate the effects of confinement, however, from the contamination of various forms of perceptual isolation is a difficult matter, since nearly all forms of confinement, and particularly solitary confinement, contain elements of perceptual isolation. By selecting experience where perceptual isolation is minimized and making allowances for its occurrence, the effects of confinement per se can be examined. They will be considered in terms of the psychological and physiological response. Tolerance of confinement and factors which modify or improve tolerance will be considered separately, later.

THE PSYCHOLOGICAL EFFECTS OF CONFINEMENT

The psychological effects of confinement can be examined in terms of the subjective response of the subject, changes in his behavior patterns, the results of psychological testing during and post confinement, ability to maintain psychomotor skills, and the capacity to complete complex psychomotor tasks.

Subject Evaluation

Subjective evaluations are undesirable sources of data under most circumstances. Unless the subjects are trained objective reporters, the quality and reliability of the reports may vary with the amount of training of the subject, his past experience, and his emotional stability. In a stressful or emotionally loaded situation such as confinement, the last factor is of obvious importance. However, because of the physical nature of confinement, particularly solitary confinement, an important source of information is the subject himself. Unfortunately, the variations in experimental methodology have been such that objective reporting of subjective reactions has not always been achieved.

The general pattern of subjective response has been examined by analysis of diaries prepared during confinement, in post confinement reports by the subject, in post confinement debriefings, and by observation.

Perceptual Aberrations: The occurrence of frank perceptual aberration is widely disseminated throughout the anecdotal and experimental literature on isolation, but very much less so in the literature dealing with confinement per se. In fact, in studies of confinement involving three men or more it is not reported. Heron [51] (1957), however, in reviewing the McGill experiments, where the purpose was to remove patterned simulation, showed that prolonged exposure to a monotonous environment has deleterious effects as evidenced by impairment of thinking, childish emotional responses, and disturbance of visual perception leading to the occurrence of both unstructured and fully structured visual illusions. Similarly Myers et al. [73] (1962), in the HUMRRO experiments, found that when their subjects were confined in a darkened soundproofed cubicle for up to 4 days, they became anxious and restless; they thought and dreamed about the past, frequently in frightening concepts; some became fearful. Many could not distinguish wakefulness from sleep.

A somewhat similar type of response with perceptual aberrations was observed in some of the subjects in the SAM one-man space cabin simulator (Hawkins and Hauty, [48] 1958). In these experiments the subjects underwent simulated space missions of durations varying from 32 hours to 7 days within a specially designed altitude chamber allowing 47 cubic feet of free volume per man. Although the intention was not to produce sensory deprivation or reduction, there was an inevitable element of perceptual isolation in the experiments. Additional stresses included simulated altitude, the wearing of a partial pressure suit, and increased CO_2 tension. Subjects were required to perform tasks on a 4 hour work rest schedule. Hawkins and Hauty [48] noted that time became oppressive to the subject in a ratio directly proportional to the duration of the flight. Intermittent periods of depression were common, and by the midpoint of the flight the subjects demonstrated a heightened sense of irritability and hostility. The boredom of the work period led to dozing during the work period and an increasing restlessness. Hauty [46] (1964) details still further some of the perceptual aberrations that developed and notes the appearance of actual hallucinations and illusions, sufficient to produce great agitation in the subjects concerned. He notes in addition that even when subjects were aware beforehand of the potential occurrence of hallucinations and illusions this did not necessarily prevent their occurrence. This led Hauty [46] to state, ". . . . the joint effects of sensory impoverishment and prolonged continuous monitoring typically will effect aberrant behavior and, prior knowledge notwithstanding, such behavior can act to compromise the functional integrity of the operator." Perhaps, however, the latter statement is a little too emphatic. It is highly significant that no disturbing illusions or hallucinations have actually been reported in one-man space flight conditions, although, somewhat surprisingly, some distortions of reality were observed by the subject in the Manhigh balloon flight. At the same time, and Hauty makes this very clear, the response of the Manhigh subject was such that, although distortions of reality and actual illusions did occur, they were recognized as illusory and did not compromise the mission. There is, no doubt, a wealth of factors differentiating the response of the Manhigh subject from that of the simulator subjects. These include motivation, morale, purposeful activity, selection and reality itself. It is not reasonable to single out any specific factor, but whatever the cause, as Hauty [46] says, ". . . . he (the Manhigh subject) did learn how to terminate these aberrancies most disturbing to him by initiating behavior that had the effect of promoting diversity of sensory effects, or, in other words, increasing sensory input."

Thus, a man, even though alone, can apparently learn to cope with perceptual aberration. However, the absence of reports on aberrations occurring among multi-man crews clearly indicates that the presence of other persons sharing the confinement tends to reduce the occurrence of disruptive thinking. With respect to the presence of other persons, however, it would appear that more than one other is necessary before an effective barrier is created. It was noted in the SAM two-man simulator experiments, for example, (Flinn et al.[29] 1961, Cramer and Flinn[19] 1963) that while there was no evidence of gross perceptual aberrations such as were seen in the one-man studies, some auditory illusions did occur among the two-man subjects.

Physical Discomfort: Apart from the emotional reactions, the sheer discomfort of confinement can be severe. The subjective response of the individual, however, varies according to whether he is closely limited by the boundaries of his confinement. Thus, in the SAM one-man space cabin experiment (Steinkamp et al.[88] 1959, etc.,), where the available volume was about 50 cubic feet, the subjects emphasized the restrictive aspects, with complaints of immobility, fixed position of the seats, discomfort from the pressure suit, general oppressiveness, etc., (Hawkins and Hauty[48] 1959). On the other hand, in the University of Georgia shelter experiments (Univ. of Georgia[34] 1962) where the available volume per man was the same, but up to 30 subjects were involved, the response was directed more towards complaints about sleeping without bunks or blankets, absence of bathing facitilies, the use of chemical toilets, the persistence of disagreeable odors, and the atmospheric conditions. Complaints about the available space were minimal. Studies where the number of subjects was intermediate and the available volume was larger showed something of both reactions. Thus, the 6 subjects in Hendler and Mancinelli's[50] (1958) report who were confined for 7 days in a converted altitude chamber with an available volume of about 75 cubic feet per man found the greatest discomfort associated with the high relative humidity (average 80%) and the odors from food and body waste; while in some of the Lockheed Georgia studies (Alluisi et al.[5] 1963) where, for example, 5 subjects were confined for 30 days in a simulated crew compartment allowing 110 cubic feet per man, they emphasized restrictive discomforts such as chafing of elbows, buttocks, head and ears. It is clear, however, that in space, because of the associated weightlessness, musculo-skeletal discomforts will be less marked, although restrictive immobility in the smaller craft will still be a problem. This is perhaps particularly so in the Gemini vehicle where mobility is even more restricted than it was in the Mercury.

Interpersonal Relationships: The subjective reaction to disturbing interpersonal relationships is a problem that besets the multi-man group, the more so when the group is small. Flinn et al. [29] (1961) remark, "It seems likely that in two-man flights, disturbances in perception will be less of a problem than gradual changes in morale and attitude, and problems in interpersonal relations." Three man groups, however, are also considered to be basically unstable since two members may unite permanently, or in shifting fashion, against the third, and disrupt the integrity of the group. Feelings of resentment and hostility either directed at individual colleagues in confinement or perhaps, more commonly, projected to the external investigators, have been fairly common in confinement and isolation research, although still more common in the latter. Reference to this has been made, amongst others, by Alluisi et al. [5] (1963) in the "HOPE" studies, Hawkins and Hauty [48] (1959) in the SAM space cabin studies, Celentano et al. [14] (1962) in the North American Aviation studies, Strope et al. [89, 90] (1960-61) in the RDL shelter studies, and the University of Georgia [34] (1963) in their studies, while in the isolation studies such as those reviewed by Solomon et al. [87] (1957), Heron [51] (1957), and Zuckerman [104] (1964) it is a frequent occurrence.

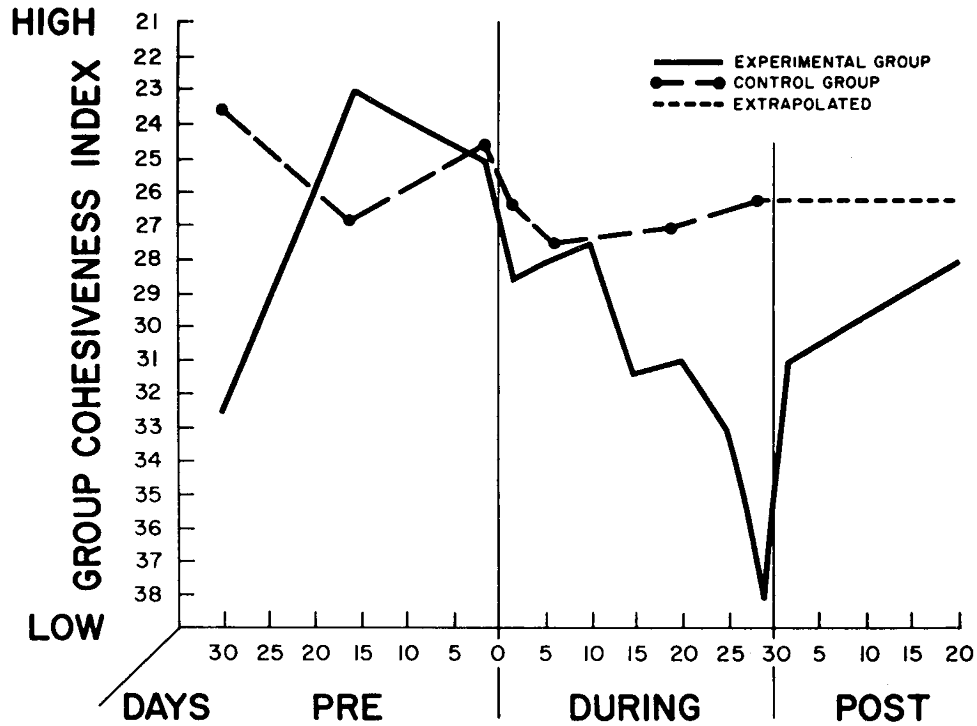
Flinn et al. [29] (1961) attempted with some success to make an objective assessment of the subjective responses of subjects in the SAM two-man chamber by means of pre-confinement psychiatric and psychological evaluation, observation during confinement and post-flight debriefings, psychologic testing, and analysis of diaries. Using independent observers, they rated the personality resources of their subjects in terms such as dependency, dominance, hostility, self-concept, emotional control and various psychological defense mechanisms.

Several objective and projective tests were completed. Inflight observation was made by television. In addition, the subjects each kept a confidential diary.

In general, the investigators found that the subjects maintained a high morale and demonstrated few emotional changes, although in each of the four pairs of subjects examined, some resentment occurred related to differing behavioral characteristics of the subjects. A taciturn subject might be irritated by a loquacious subject, who in turn would feel rebuffed. Seemingly innocuous habits and mannerisms might eventually become irritating, and trivialities of personal behavior would assume importance. Covert antagonisms would arise over status, work responsibilities, and division of duties. Open antagonism, however, rarely arose, and much of the hostility was displaced and directed towards the monitoring personnel. A similar situation is reported by Tiller and Figur [91] (1959). It is also interesting to observe that in the one-man studies (Hauty[46] 1964) similar expressions of hostility and antagonism were reported, in this case directed largely against the environment, and to a lesser extent projected to the investigators. Trivial things which the subjects would normally consider incidental assumed greater significance-haphazard storage, the clicking of an automatic camera, repetition of musical recordings. Most of the time the investigators were unaware of the hostility but later found it expressed in the diaries. It may be that in both cases the hostility is in fact an expression of another emotion, projected in the case of the two-man crews against each other, or in the case of the one-man crew, against the environment itself.

The General Electric group (General Electric [33] 1964) used a different technique in psychosocial evaluation. Having originally selected their 4 crew members from a group of 40 volunteers by a careful process of psychological, physiological, and medical testing, they were reasonably confident of the calibre of the individuals but could not predict interaction. Using a rating form consisting of a series of 24 bi-polar adjective pairs with eight degrees of response between each pair, each individual rated himself and his crewmates. To the results a statistical process was applied to produce a Group Cohesiveness Index which described the degree to which the group felt it had matters in common. The rating was applied regularly over a period of 80 days, from 30 days before beginning the 30 day simulation until 20 days after. The results are plotted in Figure 1. Comparison of the experimental with a control curve obtained from an unconfined group with the same type of independent work requiring cooperative effort shows that before confinement the crew had attained the cohesiveness found in a normal group. During the confinement period cohesiveness deteriorated steeply with a sharp rise beginning as the flight was about to end. At the same time individual personal ratings, shown in Figure 2, showed a consistent increase in stability, such that self-rating was higher towards the end of the test, and 20 days after, than it was on initiation. Thus, while there was a breakdown in group structure, the subjects individually were able to use strong emotional defenses to sustain themselves, to the extent that the decline in cohesiveness was not externally apparent, nor were covert interpersonal feelings transmitted to other crew members.

The fact that interpersonal feelings were not allowed to interfere with the success of the mission is equally characteristic of the studies of Flinn et al. [29] (1961) and Tiller and Figur [91] (1959). The significance of motivation and discipline as factors in masking the expression of hostility and resentment is obvious, but should not be relied upon to ensure success in a mission. The potential disruption of interpersonal relationships under such circumstances suggests that great care must be taken to provide mutual compatibility when selecting a group who will undergo prolonged confinement. The Russians in particular have stressed this requirement to the extent that if one member of the Voshkod crew became disabled prior to flight, the entire crew would be replaced. This policy may increase the number of astronauts to be trained for a given series of programmed missions.



Group Cohesiveness Over 80 Days

Figure 1. Group Cohesiveness Over 80 Days.

Source: General Electric (Ref. 33).

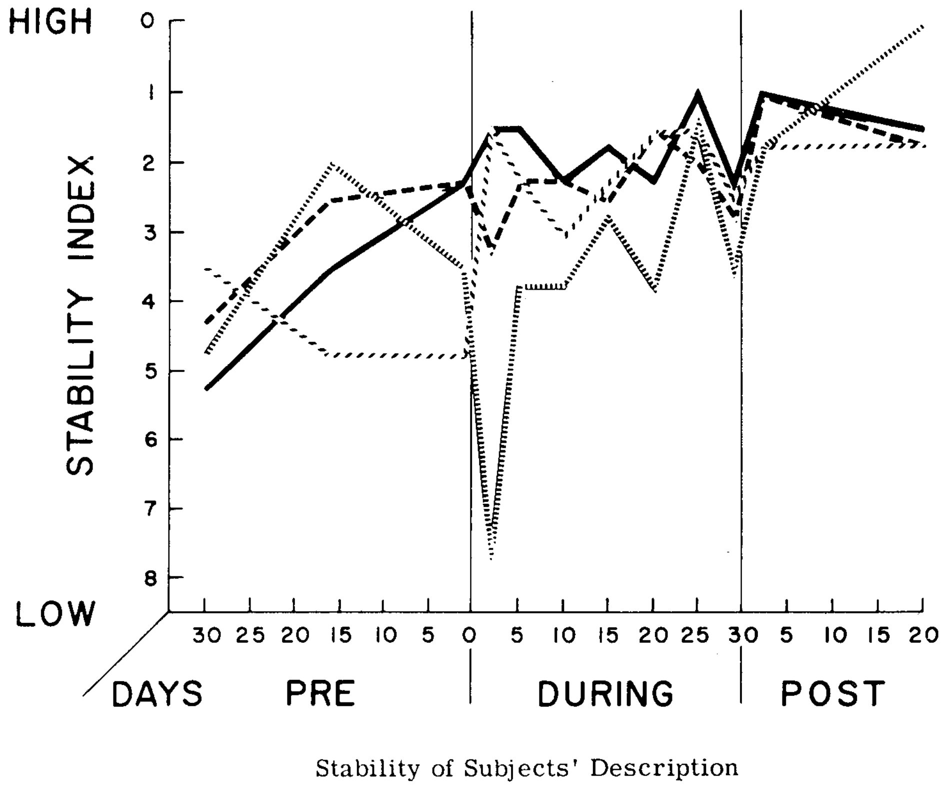


Figure 2. Stability of Subjects' Description

Source: General Electric (Ref. 33).

Psychological Measurements

Intellectual Capacity: It is characteristic of the findings in perceptual isolation studies that intellectual capacity, as represented by constructive thinking and problem solving, becomes impaired (Bexton et al. [6] 1954, Doane et al. [24] 1959, Heron et al. [52] 1956, Scott et al. [84] 1959). Where emphasis is more on the confinement aspects of the isolation situation, and less on the sensory deprivation aspect, there is less interference with intellectual function. Thus, Myers et al. [73] (1962), maintaining their subjects individually in cubicles in relative comfort, found by way of questionnaires and intellectual performance tests that while the performance of numerical facility tests, verbal fluency tests, and immediate memory tests was largely retained, a significant decrement was observed between the test subjects and control subjects on tests of inductive reasoning and successive subtraction. Efficiency recovered within three hours of leaving the cubicle. Similarly, Hanna, Burns, and Tiller [42] (1963), with six volunteer Navy enlisted men confined and restrained for periods up to 24 hours in a small isolation chamber found a decrement in response to tests of intellectual capacity, which, when subjected to analysis of variance, indicated that the parameters sampled were influenced both by the environment and by personality differences within the subjects themselves. In studies more related to the space cabin environment, where sensory deprivation does not occur, Ormiston and Finkelstein [80] (1961) sought variations in performance in 20 selected Air Force Officers each confined in an aircraft escape capsule of less than 30 cubic feet capacity. During a 48 hour confinement the subjects worked periodically on tasks involving arithmetic, digit retention, memory for confusing sentences, verbal ability tests, memory for paired-associate nonsense syllables and syllogistic logical reasoning. In addition, they were engaged in other activity, more meaningful, including simulation of aerial reconnaissance. No significant differences were observed between the test subjects and unconfined controls.

In the one-man SAM space cabin, and in further studies in the two-man cabin, Gerathewohl [35] (1959) found that the facility in performing a complex addition test actually increased during the confinement while the subjects tended to maintain much the same steadiness of performance. A similar improvement in performance of some of the tests in the Navy simulator was observed by Burns and Gifford [10] (1961). These findings suggest that the subjects were probably inadequately trained in performing the tasks before the confinement began, but demonstrates that learning can apparently take place while in a confinement stress, and indicates preservation of useful intellectual capacity. The fact that the subjects were engaged during other portions of the time in meaningful tasks leads Gerathewohl to suggest that in confinement an individual can perform perceptual tasks accurately if he is engaged in purposeful activities and well informed about his situation.

Passing to a situation similar to a long range multi-man space flight operation, the Manned Space Operation group at General Electric (General Electric [33] 1964) conducted tests on a selected 4-man crew during a closely simulated space mission. Tests included measures of higher order mental function, such as memory for digits, mental arithmetic, number retention, and again no significant decrement was observed during the simulation period as compared with a pre-simulation control runs. Similarly, Celentano et al. [14] (1962), in a 7 day space cabin study with a North American Aviation simulator, noted that no evidence of intellectual degradation was found in their studies, while Hanna and Gaito [43] (1960) found no performance decrement in complex arithmetical tasks during their 7 day 6-man space cabin simulation.

Thus, in a situation in which the sensory input is diminished, intellectual function appears to suffer, whereas in an equally confined situation with adequate sensory stimulation there is no apparent decrement in intellectual functioning. The situation then is somewhat akin to that determining the occurrence of perceptual aberration. Discussing this, Burns and Gifford [10] (1961) state, "The multiplicity of variables operating simultaneously in a confinement situation make assignmnet of dominant or major sources of influence rather arbitrary. Loss of information about external events is certainly important to the isolate. Cues as to diurnal variation and temperature changes contribute to the hypodynamic aspects of the isolate's environment. Lack of knowledge of the activities of others (friends, family, etc.) also contributes to the separation of the isolate from his normal environment.

Finally, inadequate information with regard to the isolate's performance increase his feeling of detachment and add to his insecurity." These and other various factors combine to diminish "consensual validation", as it has been termed in the "brainwashing" literature, and reduce the capacity for organized constructive thought. Consensual validation might be considered as ancillary evidence or information tending to confirm one's perceptual orientation. Thus, any factor that tends to increase consensual validation, such as the presence of colleagues, discussion on an intercom, activity on a meaningful task, routine interruptions, etc., will tend to confirm reality and assist in defining a basis for constructive thinking, and in some cases allow improvement in performance. Lack of consensual validation should not be a problem in spacecraft.

Time Estimation: Another aspect of intellectual function, again subject to consensual validation, is that of time estimation. Weybrew [98] (1963) notes the significance of time perspective in influencing morale, and quotes the early work of Gulliksen in which the latter demonstrated that inactive intervals are under-estimated. As has already been noted (Hawkins and Hauty [48] 1959) time becomes oppressive to the solitary isolate.

Mitchell [72] (1962) described time estimation experiments in the WADD isolation room, a converted anechoic chamber containing a bed, refrigerator, seat and toilet. Using 34 subjects, including 10 Air Force Test Pilots, she investigated the ability to estimate 1 second, 5 seconds, 10 seconds, and fractions of an hour up to 4 hours. The 1 second period was overestimated, 5 seconds was estimated accurately and 10 seconds underestimated, while 6, 30, 60, and 120 minutes were significantly underestimated. Some subjects went on to estimate up to 48 hours by 4 hour periods. Four hour estimates tended to become steadily shorter during the 48 hours. Some of the subjects became confused even when given a clock. Two of the subjects defected. Burns and Gifford [10] (1961) undertook some interesting studies on time estimation with the 6 subjects on the Navy simulator during an 8-day confinement. Their technique involved a measured estimate by the subjects of four different durations (15, 90, 180, and 300 seconds), but because of instrument failure only the data for the first three durations were usable. In each case there was a significant overestimation of time on the part of the experimental group as compared to a control group. In addition, the degree of overestimation increased as the length of confinement increased, although the daily increase was not statistically significant for the 15 second interval. Hanna, Burns, and Tiller [42] (1963) undertook a similar time estimation study during their work with solitary subjects in the Navy isolation chamber, measuring estimates of 15, 30, 90, 180, and 300 seconds. They found that in unconfined control sessions the 15 second interval was slightly overestimated whereas the other four intervals were moderately to greatly underestimated. During the experimental period the three shortest intervals (15, 30, and 90 seconds) were overestimated and the two longest intervals (180 and 300 seconds) were underestimated. Thus, there was an overall trend for the shortest interval to be overestimated during all sessions, including control, and for the two intermediate time intervals to be underestimated during control runs but overestimated during experimental sessions. The trend, however, did not increase with prolonged isolation. The significance of these findings is not clear, but the comparison between the consistency of overestimation during a period of active confinement in a simulator and the inconsistency during passive isolation is marked, and tends to confirm the requirement for consensual validation in time estimation.

Time estimations carried out by Grodsky and Bryant [38] (1962) in their simulated lunar mission study showed no significant difference between the confinement period and the pre-confinement period in estimations of 1, 5, 30, and 60 seconds. The authors suggest, probably rightly, that the accuracy in time estimation of their subjects in comparison with that of isolation subjects was related to the fact that their subjects were concurrently engaged in time-dependent tasks which provided an element of consensual validation.

Thus, it would seem that in isolation, with reduced consensual validation, time estimation is considerably distorted. Part of this distortion may be related to the artificiality of the task. In a situation such as confined space flight, however, where operators are of necessity engaged in time-dependent tasks and activities lending themselves to ready estimate of duration, the evaluation of passage of time is largely, if not entirely, unaffected.

Perceptual Tests: Other specific forms of perceptual ability have been investigated under conditions of confinement. Rate estimation was studied by Rathert et al. [82] (1964) during a 7-day confinement study in the NASA Ames capsule. Velocity judgments were made using three different speeds of rotation of a hand on a clock which was visible only on a portion of the face. The subject estimated time of arrival of the hand at a hidden point. Although only two subjects were used, and some inconsistenci s occurred in the results, there seemed to be a trend towards a decrement in performance as confinement proceeded.

Rathert et al. [82] (1964) also studied a pattern discrimination task in the same experiment. Patterns were made by arrays of dots produced by a computer. A pattern, followed after a short period by a comparison pattern, was presented to the subject. The comparison pattern was rotated 180^{o}. The subject determined if the patterns were similar or dissimilar. Performance improved during the first three days and then deteriorated; but as the authors suggest, a lack of inherent interest in the task no doubt contributed to the deterioration.

Ormiston [79] (1961) undertook some interesting illusional tests with subjects confined eight hours in a lighted cubicle. These consisted of demonstrations of the Phi phenomenon, response to a Necker cube, demonstration of autokinesis, and of a spiral after-effect. In comparisons between confined and unconfined subjects no difference was found in frequency of flash for perception of the Phi phenomenon, nor in response latency to autokinesis. Confined subjects showed significantly fewer reversals of the Necker cube, while unconfined showed an increase. For the confined subjects the duration of spiral after-effect lasted significantly longer than for the unconfined. In the latter the duration decreased. The significance is obscure. Similar results in spiral after-effect were observed by Doane et al. [24] (1959).

Reaction Time: Reaction time has not been a fruitful source of information in confinement. In the work of Chiles [16] (1955) also reported by Dempsey et al. [22] (1956), which involved an element of isolation in that four subjects were individually maintained in an aircraft cockpit for 56 hours, reaction time was measured as the time to cancel a panel light. Since the subject received no warning, there was a vigilance factor involved in the test. Results showed a wide range of response, from 0.6 to 90 seconds with a median of 15 seconds. Ten percent of the responses took longer than 6.1 seconds. No trend, however, was observed with duration of confinement.

The General Electric group (General Electric [33] 1964) removed the element of vigilance from their reaction tests by providing a visual warning signal before beginning the tests. Both simple and choice reaction time were measured, four choices being provided in the latter. No significant change in performance occurred over the 30 day time interval. Unfortunately the results obtained were not compared with a pre-run control.

Grodsky and Bryant [38] (1962) used another form of test in which, after a warning signal, a panel clock was started externally and had to be stopped by the subject after a given time (1, 5, 15 seconds). Comparison between pre-run control and experimental tests showed no significant differences. Thus, although no trend occurred with confinement, it cannot be stated categorically that confinement causes no change in reaction time. The wide range of response in the Chiles [16] study, and the greatly prolonged response time in some instances, is also open to mixed interpretation because of the element of vigilance involved. The prolonged re ction which was demonstrated by Dempsey [23], is, however, of considerable practical significance in that it demonstrates that in more than 10% of cases a warning light might go unobserved for over 6 seconds, and in some cases for over 90 seconds, despite a readily visible location on the lower left corner of the instrument panel.

Vigilance: Tests of vigilance have been popular means of determining alertness or fatigue. Measures of other types of auditory or visual vigilance, or both, have been reported by Celentano et al. [14] (1962), by Rathert et al. [82] (1964), General Electric [33] (1964), Adams and Chiles [2] (1960), Adams and Chiles [3] (1961), Chiles [16] (1955), Myers et al. [73] (1962), and Burns and Gifford [10] (1961). In general, although there was some variability, vigilance was not affected under the conditions studied. In the Adams and Chiles [3] (1961) study, which was primarily a study of work scheduling using a four hour on and two hour off schedule, there was a decrement related to the duration of confinement. Because of the severity of the schedule, however, this decrement might represent the results of scheduling fatigue. An interesting comment also comes out of the Myers et al. [73] (1962) study. While the performance of the confined group in auditory vigilance tests when working in a lighted cubicle was not significantly better than that of an unconfined group working in light, it was significantly better than that of an unconfined group working in the dark. In other words, the effect of the confinement per se is probably of less significance than the nature of the conditions in which the confinement is undertaken. The criticality of the task is probably another significant factor.

Monitoring: Various forms of monitoring have been measured, some of which are more in the nature of vigilance studies, (Chiles [16] 1955; Dempsey et al. [22] 1956; Celentano et al. [14] 1962; Burns [9] 1959), and some of which have elements of tracking (General Electric [33] 1964). A straight monitoring study was described by Rathert et al. [82] (1964) which involved response to a display representing mission status. The results of these studies are somewhat variable but no evidence of gross deterioration has been noted, and in fact, in the General Electric study and the NASA study performance actually improved with time.

Tracking: Tracking tasks of different types as measures of psychomotor performance have been examined by numerous groups, including Steinkamp et al. [88] (1959) in the SAM simulator, Burns [9] (1959), and Burns and Gifford [10] (1961) in the Navy simulator, Ormiston [79] (1961) in the WADD cubicle, Ormiston and Finkelstein [80] (1961) in the WADD escape capsule, Celentano et al. [14] (1962) in the NAA simulator, and Rathert et al. [82] (1964) in the NASA simulator. With the exception of the studies by Steinkamp et al. [88] (1959) no appreciable decrement in tracking performance was evident. In Steinkamp's study one of the four subjects, who was a capable airman but inexperienced in the stresses associated with prolonged high performance flight, showed a decrement in performance with time. It is malfunctions and emergencies were introduced. Two missions were completed with different work-rest schedules, the second mission having a more tolerable duty cycle. Crew performance was measured during the dynamic flight phases and compared with baseline landings, lunar ascent and orbit rendezvous, and re-entry. No degradation in pilot performance was observed and no deterioration in alertness, as measured by response to emergency, was noted, although pilots tended to forget certain procedures at times, perhaps from inadequate training.

Grodsky and Bryant [38] (1962) report the results of the same mission and two previous missions of $3\frac{1}{2}$ days. During these mission, in addition to certain specific psychological and physiological measurements, data were obtained on performance in flight control tasks, systems management tasks, detection of malfunctions and navigational tasks. Comparison was made with baseline performance data obtained during a 10 week period prior to the flights. In general, no major decrement occurred in performance, although quite a number of procedural errors occurred during each of the flights, gradually diminishing between the first and the third flights. The nature of the errors, however, which were largely of the type of forgetting the sequence of procedures, and the fact that errors tended to occur sporadically, suggests that errors were not so much associated with confinement as with lack of training and lack of practice during the "resting" portions of the flight. Some of them also probably indicated poor information display.

The General Electric group [33] (1964) included a rendezvous and docking task in their four man 30 day simulation program, utilizing a stationary simulation by computer for the task. The task included a search procedure, followed by acquisition of the vehicle. Measurements were made of the ability of the subjects to reduce the closing rate of the vehicles to near zero velocity at a specified range, and to maintain a satisfactory vehicle attitude, while note was also taken of the total rendezvous time and the cumulative thrust duration. Most of the rendezvous maneuvers were successfully completed. For the docking simulation, the General Electric five-degree-of-freedom simulator was employed with a television presentation. The same control system was used for rendezvous and docking. In all cases perhaps surprising that Ormiston's subjects who were isolated in a cubicle showed no decrement in tracking performance, but this may be related to the relatively short (eight hours) duration of the confinement.

Complex Performance: While measurement of performance skills and psychological attributes is valuable in determining specific response to a stress, the ability of a subject to perform the mission required of him is of practical concern. Several of the simulator studies have employed task systems that represent the actual type of activity that would be required in a space mission. McKenzie et al. [68] (1961) in the SAM two-man simulator, described predominantly visual tasks. These were disposed across three panels to produce a multivariate system which included some fairly standard approaches to psychological testing. The system was given a degree of space flight verisimilitude by assigning to portions of it terms such as Navigation or Orbital Computer, Airborne Radar and Doppler Position System, Reaction Control Monitoring System and Data Telemetry System. The effect on response times of frequency of signal, length of work period, and flight duration was measured during a 17 day and a 30 day flight. In the 17 day flight there was a steadily increasing average response time which, however, was not obtained in the antecedent 30 day flight. The authors attribute the difference to one or both of two variables, namely, that the 17 day flight was maintained at a simulated 33,000 feet altitude instead of 18,000 feet, and that the 17 day flight was the second extended flight for the subjects within a short period. Since the pO_2 in each case was held constant, it is unlikely that variation in altitude made any significant difference. A considerable diurnal difference in response time (longer at night) was observed which reflected the effects of diurnal cycling, and extended work period during the night, and changes in signal rates. A separate analysis for a varying signal rate showed an inverse relationship between the number of responses made in a given period and the average response time during that period.

Mallick and Ream [69] (1963) described the work during a 7 day simulation with the Martin Baltimore lunar mission simulator which incorporated the Langley Research Center one-man "bug". Displays, tasks, and activities represented those of the mission. To provide further realism, various the docking maneuvers were successfully completed and proficiency improved with time.

In the NASA Ames studies reported by Rathert et al. [82] (1964), in addition to some of the other tests discussed before, a navigation task was required of the subjects, based on an emergency midcourse guidance system in which the astronauts photographed the earth's disc and star background and thereafter calculated the trajectory. The ability of the subjects to make the necessary photographic measurements remained satisfactory throughout the confinement period. The performance of the mathematical computation was not satisfactory, probably because of improper design of the procedure and inadequate training, rather than confinement per se.

Other Coordinated Tasks: In another area of confinement investigation, Hicks [53, 54, 55, 56, 57] (1960a, 1960b, 1961a, 1961b, 1962) carried out a series of studies on the efficiency of soldiers who had been confined for various periods under severe environmental conditions in an Armored Personnel Carrier. Before and after confinement he measured their performance on complex activities, such as an obstructed run course, a rail walking course, grenade throwing, and rifle firing. Little effect was observed with a four hour confinement, but with increasing duration from four hours to 24 hours, sometimes with mounting heat and humidity, noise and buffeting, there was an increasing decrement in performance. One of the tests, of 12 hours duration, was undertaken in a stationary vehicle without motion, noise, or vibration. During the first five hours of this test no air conditioning was provided and the effective temperature rose to 100° F. During the remainder of the run, however, ventilation was provided and a reasonable environment was maintained. Consequently the test represented a stress provided mainly by confinement, although sequelae from the heat stress cannot be entirely disregarded. This particular test resulted in statistically significant performance decrements representing loss in equilibrium (rail walking), loss in stamina and locomotor coordination (obstructed run), loss in grenade throwing accuracy, but no observable change in rifle accuracy.

From examination of the results of these complex coordinated tasks it would appear that within the durations studied, and under conditions simulating to some extent actual space flight vehicles, the ability of the crew to perform meaningful tasks is not impaired by confinement per se. When the available volume is reduced, however, to intolerable or barely tolerable limits, as in the case of the Armored Personnel Carriers, task performance is impaired.

The occurrence of procedural and computational errors points up the necessity of careful consideration of task design and training procedures and suggests that in the longer flights training should be continued during the mission.

The "HOPE" Studies. The psychological effects of confinement cannot be left without reference to the studies conducted in the Lockheed Georgia crew compartment mock-up by Adams, Chiles, Alluisi, and their colleagues (Adams and Chiles [2] 1960; Adams and Chiles [3] 1961; Alluisi et al. [5] 1963; Alluisi et al. [4] 1964) to which some casual reference has already been made. These studies, which began essentially with a study labelled OPN-360 and went through studies termed HOPE-II to HOPE-VII, were primarily neither confinement studies nor mission simulation, but were designed to determine the effects of varying work-rest cycles. They did, however, involve aspects of confinement in that crews of varying numbers and experience were maintained for periods varying from 96 hours to 30 days under various conditions of work within a mock-up comprising a five station work area, a leisure area, and a sleeping area, and presenting a total volume of approximately 1100 cubic feet. Depending on the number of occupants this permitted about 100 to 180 cubic feet per man.

To summarize the results it is convenient to paraphrase the words of Alluisi et al. [4] (1964), who point out that in the preparatory studies (Adams and Chiles [2] 1960), the performance of 16 subjects was measured over 96 hours on four different work-rest schedules. The subjects were tested in groups of eight in a flight systems mock-up which was distributed within a laboratory and occupied a total volume of less than 1000 cubic feet. This was not a true confinement study, however, in that the various working and sleeping areas were located in different parts of the laboratory, and also since the subjects left the laboratory for meals. The results suggested that for active and passive work a two hour or four hour shift was superior to others. Two additional 96 hour experiments followed, which included investigation of a 6-2 schedule. This schedule allowed less than four hours of sleep per day. Questionnaires from the subjects indicated that severe performance decrement would have resulted from prolongation of the exposure beyond 96 hours.

Operation - 360 (OPN-360) was the first of the long-term investigations (Adams and Chiles [3] 1961). Two crews of operational personnel were separately confined in the 1100 cubic feet crew compartment on a 4-2 schedule for 15 day periods. This experiment included complete confinement, and elements of mission simulation. A subsequent control study was carried out with six subjects working four hours per day, five consecutive days per week, for six weeks. Well-marked diurnal rhythms were observed, and fatigue and emotional reactions noted. The trends in the confined group, in comparison with the control group, suggested that, with a minimum of selection, motivated subjects could produce levels of performance on a 4-2 work-rest schedule that would be acceptable for at least 15 days.

The second and third long term investigations, HOPE-II and HOPE-III (Alluisi et al. [5] 1963) added group performance tasks to the activities. These required interactions among crew members in the form of exchanges of information, cooperation, and group coordination. In HOPE-II, six subjects followed a 4-2 schedule for 15 days while in HOPE-III ten pilots followed a 4-4 schedule for 30 days. Again it was shown, that with high motivation, a 4-2 schedule could be maintained for 15 days with acceptable decrement. Performance, however, was better sustained on a 4-4 schedule for a 30 day period.

In tests HOPE-IV and HOPE-V (Alluisi et al. [4] 1964), ten subjects were confined for 12 days on a 4-4 schedule following the same program as HOPE-II, except that during the sixth and seventh days subjects worked continuously for 44 hours. In HOPE-VI and HOPE-VII (Alluisi et al. [4] 1964) six subjects were confined for 12 days on a 4-2 schedule using the HOPE-II program, and again in this case worked continuously for 40 hours during the sixth and seventh days. In both cases, the sleep loss resulted in significant performance decrement, which was greater on the 4-2 schedule (HOPE-VII) than on the 4-4 HOPE-VI. Performance returned to approximately the level expected had there been no sleep loss after the subjects on the 4-4 schedule had obtained two sleep periods and after those on the 4-2 schedule had obtained three sleep periods.

This work would indicate, inter alia, that for optimum performance with minimum crew, a schedule of four hours work alternating with four hours rest is a requisite. It is not the intention to discuss here problems of work-rest scheduling, but in passing it is noted that a 4-4 schedule was used effectively in the SAM one-man simulator (Steinkamp et al. [88] 1959) and the NASA Ames study (Rathert et al. [82] 1964). The General Electric Group [33] (1964) used an individualized cycle system on a 24 hour day, while Grodsky and Bryant [38] employed two systems in their studies, one allowing eight hours sleep, six hours relaxation, and 10 hours work in a 24 hour day, and the other allowing two separate four hour sleep periods, 10 hours work and eight hours relaxation in a 26 hour day. The SAM two-man studies (McKenzie, et al. [68] 1961) used a complex system in which each day the simulator was internally manned for 22 hours, the remaining two being controlled from the ground. Each subject manned the operator system for a three hour period in the mornings, a two hour period in the afternoons and a five hour work period at night, along with an extra two hour period every other day. Six to seven hours of sleep were allowed per person and the remaining time was mostly free.

<u>University of Maryland Programmed Environment</u>. Another study requiring specific attention is that carried out by the Institute for Behavioral Research of the University of Maryland, assisted by the Walter Reed Army Insitute of Research (Findley et al. [27] 1963). In that considerable space and area were involved, (1368 cubic feet, 171 square feet), the restrictive aspects of this study were minimal. In fact, it was not so much a study of confinement as a

study of the response to an environment in which every activity on the part of the subject was programmed for him on the basis of satisfactory sequential performance; the effect is something analogous, although much more complex, to the reward or punishment achieved by a chimpanzee after making the correct motion of a lever. The principles and techniques of the animal laboratory were incorporated into the design of the experimental environment whereby requirements or contingencies were programmed in such a manner that the behavior of the subject produced pre-programmed changes in the environment. Particular behaviors had given consequences, but only if these forms of behavior were manifested under specific stimulus conditions. The environment differed fundamentally from a normal environment in that opportunities for various kinds of activities were available only as specifically provided for by the behavioral program.

The chamber consisted of three interconnected rooms, one room 11 feet x 11 feet, and two small rooms 5 feet x 5 feet. All three were 8 feet in height. The rooms were air conditioned, with the temperature maintained at 75° while the subject was awake and 70° asleep. Sound attenuation was provided. The chamber was normally illuminated except during parts of the program when the lights were extinguished. A decorative appearance was provided. The main room contained a bunk, table and chairs, a lounge chair, automatic equipment and consoles, along with small pieces of equipment and storage drawers. One small room was a special work room and the other contained full toilet facilities. Access to the small rooms was available only on a programmed basis except for limited toilet use. To maintain himself, and provide recreation and rewards, the nature of which might be unknown, the subject was required to perform various activities in a programmed order as directed by console indicators. The type of activities, and their initiation, was either automatically controlled or under the direction of outside investigators. Communication from outside was limited to the minimum. Performance changes were recorded in terms of frequency of selection of activities, duration of activities, and other quantitative and non-quantitative measures.

A subject was maintained in this environment for 152 days until cumulative stress led to his defection. In the course of time, behavioral decrements occurred, including increasing hostility, increasing frequency of toilet use (where the subject was left to his own resources in privacy), increasing frequency of general negative complaints, somatic complaints, and requests for health items, increasing frequency of sleep, increased duration of toilet operations and eating, and declining time in creative activities. The authors consider that these behavioral decrements were due more to social isolation than to confinement per se, and this belief seems to be justified, although definitive results cannot be obtained from one subject.

To summarize the psychological response to confinement, excluding as much as possible the factor of perceptual isolation, and bearing in mind the varying methodologies involved in the experimentation, it would appear that the effects are manifested initially as subjective emotional reactions, such as hositility and resentment, directed in the case of the solitary isolate largely against the environment and investigators, or in the case of multiple confinees, against their colleagues. Where restriction of movement is paramount, subjective discomfort can be severe. Perceptual aberrations are not apparently a feature of confinement but occur as a result of reduced sensory input. Performance decrement, intellectual or complex psychomotor, is relatively slight, and probably results either from fatigue arising from demanding work schedules, or from boredom associated with performance of repetitive and apparently useless tasks. Simulator experiments have shown that provided available space is above a given threshold, and this will be discussed later, a selected and highly motivated crew, in spite of discomforts and covert hostilities, can maintain performance levels for in-flight activities with only moderate decrements for simulated missions of at least 30 days. The effect of the additional stresses which will occur in actual space flight can only be guessed at, but there is no doubt, for example, that weightlessness will relieve some of the distresses of restriction, while exhilaration and fear will modify some of the emotional reactions.

THE PHYSIOLOGICAL EFFECTS OF CONFINEMENT

Assuming an acceptable level of ventilation, temperature, humidity and other extraneous environmental factors, the physiological changes associated with confinement might be expected to result from the physical limitation of activity imposed by the restricted environment, and from changes induced by the subjective reactions to confinement. It is well known to the clinician that prolonged inactivity gives rise to a generalized hypofunction, manifested particulary in the cardiovascular and musculoskeletal systems. Because of this, fears have been expressed over the potential effects of weightlessness in this regard, and numerous studies of simulated weightlessness, along with observations on astronauts and cosmonauts, have shown these fears to be well grounded. Lamb et al. [63] (1964 a), however, have made the very pertinent point that all hypogravic studies have of necessity included inactivity as a major factor in the simulation, and until the effects of the inactivity per se have been evaluated the contribution of weightlessness cannot be properly assessed. The cardiovascular response to confinement thus becomes of considerable significance in assessing the overall response to space flight.

Cardiovascular Studies

Numerous investigators have monitored cardiovascular activity during and after confinement. There is no doubt that under conditions of severe confinement, approaching immobilization, there is evidence of fairly extensive cardiovascular deconditioning. Bed-rest studies, representing near extremes of immobilization, and certainly restrictive confinement, have been conducted by Birkhead et al. [7] (1963), Miller, Hartman et al. [70] (1964) and Miller et al. [71] (1964). The studies of Miller and his group, for example, showed that during periods of two to four weeks flat bed rest, orthostatic tolerance, which represents the capacity of the cardiovascular system to adapt to changes in hydrostatic pressure, was considerably reduced. To demonstrate, however, that the deconditioning was not solely a function of the supine posture Lamb et al. [64] (1964 b) maintained six healthy subjects restrained in arm-chairs for four days in such a manner that they required minimum effort to support their own weight. Two of the subjects demonstrated orthostatic intolerance on the tilt table after confinement to the chairs.

The hydrostatic pressure head in the terrestrial situation is proportional to the length of the column of liquid. Consequently, in the supine position, as compared to the erect position, the pressure head between head and feet is practically negligible, and it would seem reasonable to assume that in bed-rest, deconditioning is associated with the reduced requirement for the cardiovascular system to combat the pressure head. In the seated position, however, the pressure head is about two-thirds that in the erect. Since deconditioning also occurs in the seated position it would seem that other factors are involved in loss of conditioning besides a drop in the pressure head. The factors involved no doubt include loss of blood volume mediated through fluid volume receptors. Other factors may involve disuse atrophy of muscle and diminished action of the muscle pump.

While mobility is very restricted in bed and in a chair, it is somewhat less so in a space cabin, although in the smaller cabins opportunity for translational movement is minimal. To determine whether deconditioning actually occurs under these conditions, Lamb et al.[63] (1964 a) made a retrospective study of the findings of 36 subjects confined in the SAM space cabin simulator for various experiments. The measurements were not the result of a planned investigation but were incidental to specific simulator experiments in which different groups were confined for 14, 16, 17, or 30 days, during which they were frequently seated, had regular sleep periods, and were very limited in physical activity by the size of the cabin. Specific measures for most of the subjects included a double Master's test pre- and post-run, treadmill studies, and tilt table tolerance with accompanying measures of heart rate and blood pressure. The tilt table protocol incorporated a baseline heart rate by EKG, and the measurement of blood pressure in the horizontal position. The subject was then tilted to the perpendicular, usually slung in a parachute harness. Thereafter, EKG and blood pressure were obtained at each minute of orthostasis. This was followed by breathholding and hyperventilation tests during a maximum duration of about 20 minutes orthostasis. In addition, most subjects underwent pre- and post-confinement cholesterol determinations, body weight measurements, and determinations of hemoglobin, hematocrit, red blood

Table 2. Changes in Treadmill Studies

Subject	Time before	Change (min.)	Maximum O_2 consumption before (cc.)	Maximum O_2 consumption after (cc.)	Change (cc.)
A1	11	+3			
A2	17	-2			
A3	18	0			
A4	15	+1			
A5					
A6					
B1	17	+1	2500	2500	0
B2	16	-1	2400	2900	+500
B3	12	0	2000	2000	0
B4	11	0	2700	2400	-300
B5	11	-2	2050	2050	0
B6	14	-6	2100	1800	-300
B7	15	-4	2700	2100	-600
B8	18	-4	3000	2300	-700
C1	16	-4			
C2	14	+1			
C3	14	+1			
C4	13	+2			
C5	14	-2			
C6	13	-4			
C7	15	-2			
C8	16	-2			
D1	17	-2			
D2	17	-1			
D3	16	+1			
D4	10	0			
E1					
E2					
F1	16	-4	3000	2100	-900
F2	18	-3	3200	2600	-600
F3	17	-7	2600	2000	-600
F4	18	-7	2600	2500	-100
G1	21	-6	3600	3100	-500
G2	16	-7	2300	1700	-600
G3	13	-4	2500	2100	-400
G4	19	-9	3300	2300	-1000
Mean change		-2.3			-381.0

Source: Lamb et al. (ref. 63)

Table 3. Heart Rate Changes During Orthostasis After Confinement

	Baseline	12 minutes	16 minutes	20 minutes
Mean change	-0.3/min.	+10.0/min.	+12.8/min.	+6.2/min.
Number of subjects with decreased heart rate	12	5	3	7
Number of subjects with unchanged heart rate	8	7	4	3
Number of subjects with increased heart rate	12	19	20	15

Source:Lamb et al. (ref. 63)

cell count, blood volume, plasma volume, and red blood cell mass, while some had oxygen consumption studies from measurements made during exercise on a treadmill.

In these subjects, cardiovascular deconditioning after confinement was manifested by decreased blood volume, decreased hemoglobin, decreased exercise tolerance as shown by an increase in pulse rate after a Master's exercise tolerance test, decreased exercise endurance on the treadmill, decreased maximum oxygen consumption, and decreased orthostatic tolerance.

Specifically, blood volume as measured by the I-131 dilution technique showed a decrease in 15 out of 17 subjects; hemoglobin decreased in 22 out of 26 subjects; hematocrit decreased in 28 out of 32 subjects. In the treadmill studies, the time required to reach a heart rate of 180 to 200 decreased in 21 out of 32 subjects, being reduced in some cases by six or seven minutes, while maximum oxygen intake was decreased in 12 out of 16 subjects. The data are shown in Table 2, which indicates for all subjects the time to reach threshold for pre-confinement subjects, the change in time post-confinement, and in some subjects the O_2 intake.

The tilt table studies are particularly interesting. Pertinent data are shown in Table 3 which, allowing for those defecting by reason of syncope (seven subjects), shows an increasing heart rate with duration of exposure to tilt. At the same time the number of subjects with decreasing pulse pressure shows a progressive increase, while the systolic pressure tends towards decrease. Pre-confinement, no subject demonstrated a syncope during the first 12 minutes of exposure whereas post-confinement four subjects (11%) had syncopal episodes in less than 12 minutes. In total, nine subjects demonstrated syncope post-confinement as against four pre-confinement.

As another manifestation of deconditioning, although the conditions and volume of the cabin are not clearly stated, the Russians (Lebedinskiy et al.[65] 1964) showed that after 10 to 15 days of confinement the cardiac stroke volume decreased from 50 to 40 ml. and the minute volume decreased from

3.75 to 2.7 liters. Under physical loading conditions (unstated) these indices did not reach the level of pre-confinement controls. A three minute delay was observed in return to normal.

None of the other groups concerned with confinement studies would appear to have made a specific study of deconditioning in confinement, but it is interesting to note that Steinkamp et al. [88] (1959), before the problems of confinement deconditioning had been examined, observed that the post-flight circulatory studies on subjects in the one-man simulator resembled the pattern found among convalescent patients during prolonged bed-rest. Celentano et al. [14, 13] (1962, 1963), in their studies with the North American Aviation simulators, where the smallest allowed about 65 cubic feet per man, observed that subjects experienced a rise in blood pressure and increase in heart rate on leaving the cabin, along with complaints of dizziness, weakness, and fatigue in walking, and that the symptoms resembled those found on bed-rest. From the above discussion, it would appear that the cardiovascular deconditioning is related to the degree of restriction in the confinement.

Where more space is available there is more mobility, and confinement is less extreme. In Grodsky and Bryant's [38] (1962) Manned Lunar Mission study where each occupant had about 135 cubic feet of space, no deterioration was observed in the post-confinement performance of athletic endurance tests nor of the Harvard step test. The latter was scored both in terms of number of steps per minute and maximum heart rate attained. Similarly in the 30 day General Electric mission (General Electric [33] 1964) no significant decrement was observed in the performance of an exercise tolerance test. In both of these simulations, however, the situation was complicated by the addition of strenuous exercise to the protocol. In the former case the exercise was in the form of an organized program, whereas in the latter the daily tolerance test was in itself a fairly strenuous exercise.

Changes in heart rate, however, are by no means due only to deconditioning. Adaptation to a new environment, diurnal variation, and emotional stress have all been observed as influencing factors. An initial rise followed by a progressive decrease in heart rate was observed in studies, where other manifestations of deconditioning were not obvious, by Hanna, Burns, and Tiller [42] (1963), Hanna [41] (1962), Alluisi et al. [5] (1963), Adams and Chiles [3] (1961), Celentano et al. [14] (1962), Gorbov et al. [37] (1964), and probably represents an emotional response to the stress of a new environment. The effects of diurnal variation have been remarked on by numerous investigators including in particular Alluisi et al. [5] (1963), Adams and Chiles [3] (1961), and Hanna et al. [42] (1963). As another manifestation of emotional response, Hanna [41] (1962), in another paper, showed that the initial rise in heart rate was followed by a progressive fall, which in turn was markedly interrupted on the fifth day of his particular study when a serious emergency was deliberately introduced into the simulation. Emotional affects are also probably reflected in the rise in pulse rate that tends to occur on the last day of confinement. In the Gemini missions, in which weightlessness, and no doubt, emotional stress were complicating factors, the heart rate showed an initial rise which stabilized in 36-48 hours, with marked diurnal variation, and rose again 2-3 orbits before retrofire.

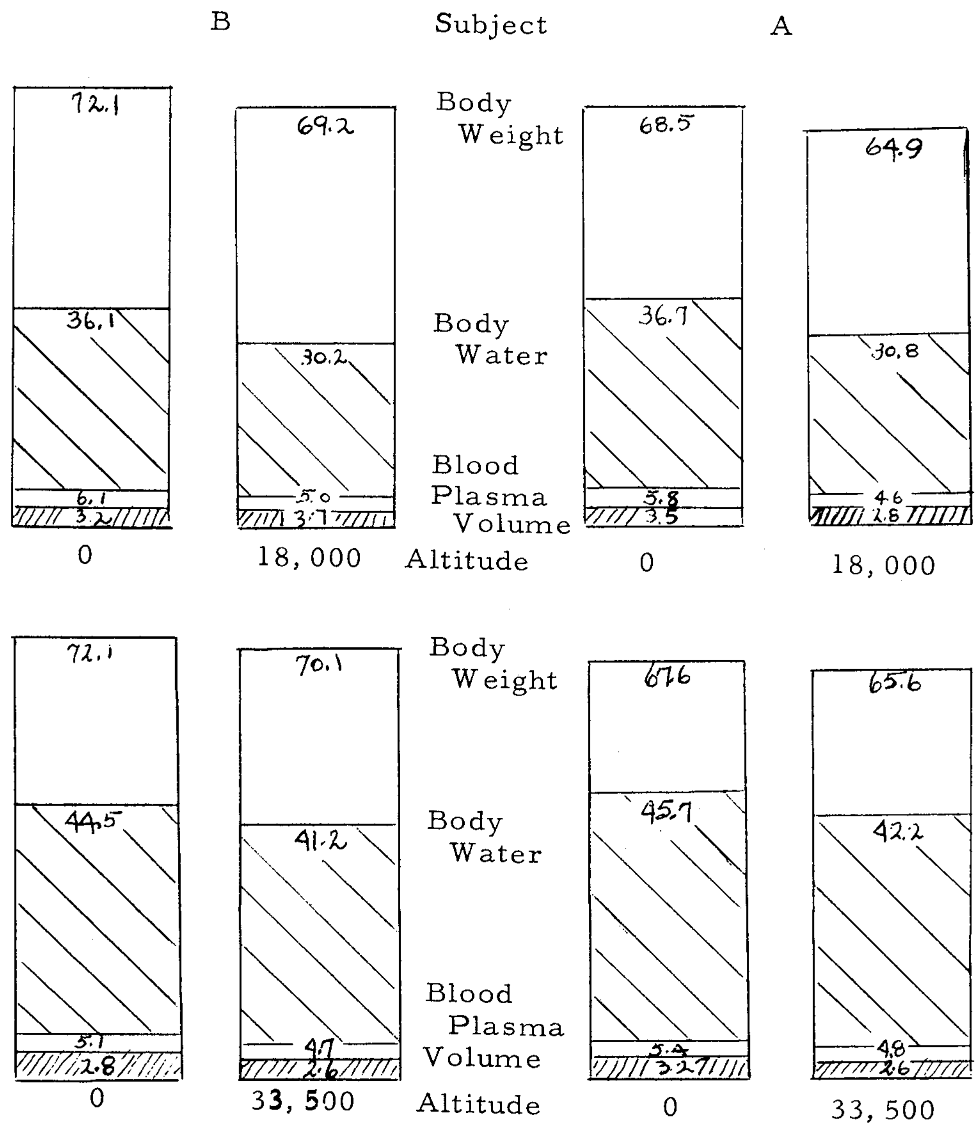
Thus, in summary, confinement within a region of very limited movement, as in a space cabin where the available volume is minimal, can give rise to gross manifestations of cardiovascular deconditioning, even within the terrestrial gravitational environment when the subject is free to stand and move in a limited manner. Weightlessness might be expected to aggravate the deconditioning.

In addition, confinement gives rise to cardiovascular changes characteristic of the response to non-specific stress.

Fluid and Blood Volume and Body Weight.

Loss of blood volume during confinement has already been noted in the studies reviewed by Lamb et al. [63] (1964a). The basis of some of these observations was the work of Morgan et al. [74] (1961) in the SAM two-man simulator. They observed weight loss together with decreases in total body water, total blood volume, and plasma volume (Table 4). Loss of total body water, however, was larger than the corresponding loss of weight and was no doubt contributed to by increased sweat evaporation at altitude. The authors suggest that the discrepancy between loss of body water and loss of body

Table 4. Body Fluid Compartments After Altitude Exposure



Source: Morgan et al. (ref. 74)

weight might be attributed to a change in body composition towards a greater proportion of fat. They note that two mechanisms seem to be involved in the weight loss, since on completion of a 17 day confinement a rapid recovery of weight ensues, as contrasted with a slow long delayed recovery after 30 days confinement. They suggest that the weight loss occurring with the shorter period might be primarily associated with dehydration, whereas in the longer period the weight loss might be associated with altered cellular composition. Loss in plasma volume was observed in Gemini IV and Gemini V, and was accompanied by other evidence of dehydration and reduced water intake. In Gemini VII, where water intake was maintained, no loss in plasma volume was observed (NASA [78] 1966). How much of this water loss is actually due to diuresis and how much to loss via other routes is not clear. Morgan et al. [74] (1961) noted results within the normal range in renal function studies, and no evidence of hemoconcentration as observed by the hematocrit and plasma osmolarity. At the same time, a decreased hematocrit was observed in some of the other studies examined by Lamb et al. [63] (1964a) and Celentano et al. [14] (1962), while of course, if both cells and fluid are reduced proportionately, the hematocrit will be unchanged. The kidney, however, may not be the only source of water loss. The General Electric Group [33] (1964), conducting water balance studies, found a water imbalance representing at least 30 cc/man/day (Table 5), provided largely by an increase in water lost via the skin and respiratory system. Considerable evaporative losses were also observed by Rathert et al. [82] (1964). Thus, while the fluid loss may be initially mediated by diuresis it seems that it may be maintained, in addition, by other routes.

A strong trend towards decrease in body weight has been observed in most studies, and in space flights particularly where conditions were extreme, but not in all subjects in these studies. How much is due to loss of body water and how much due to reduced or altered diet is debatable. There is no doubt, for example, that in the University of Georgia studies [34] (1963), the diet of 300 to 800 calories per man per day must have contributed greatly to the ensuing loss of weight, while in other studies muscle atrophy associated with disuse is also a factor. Lamb et al. [63] (1964a), in their review, observed a relationship between age and body weight response. Of the 25 subjects examined, 19 had a weight loss despite an adequate available diet. The remaining six, aged 17 to 21, had no weight change. The explanation of this finding, is obscure, unless it merely represents a difference attributable to a healthy young appetite.

TABLE 5

Average Water Balance

	Normal (Liters/Man/Day)	Test (Liters/Man/Day)
H_2O Turnover	2.5	2.6
H_2O Urine and Feces	1.65	1.17
H_2O Skin and Respiratory	0.85	1.46
H_2O Balance	-0-	-.03

Source: General Electric (Ref. 33).

Energy Requirements

Consideration of weight loss and diet brings up the question of energy requirements. Accepting an energy expenditure of about 2000 kilocalories per day at bed-rest in a thermoneutral environment, it is reasonable to assume that energy requirements under fairly severe confinement must be somewhat similar. This is to a certain extent confirmed by Rathert et al.[82] (1964) who calculated, on the basis of oxygen consumption studies, that their two subjects had mean energy expenditures of 1991 and 1754.4 kilocalories per day respectively, and in fact the caloric intake of these subjects on an ad.lib. diet approximated the requirement. The subjects in this study undertook a daily exercise program of pushups, running in place, and arm and leg movements. Welch et al.[94] (1961), on the other hand, whose subjects did not undertake programmed exercise, found in studies in the two-man SAM simulator, that the dietetic demand was considerably less, averaging 1726 kilocalories per man per day.

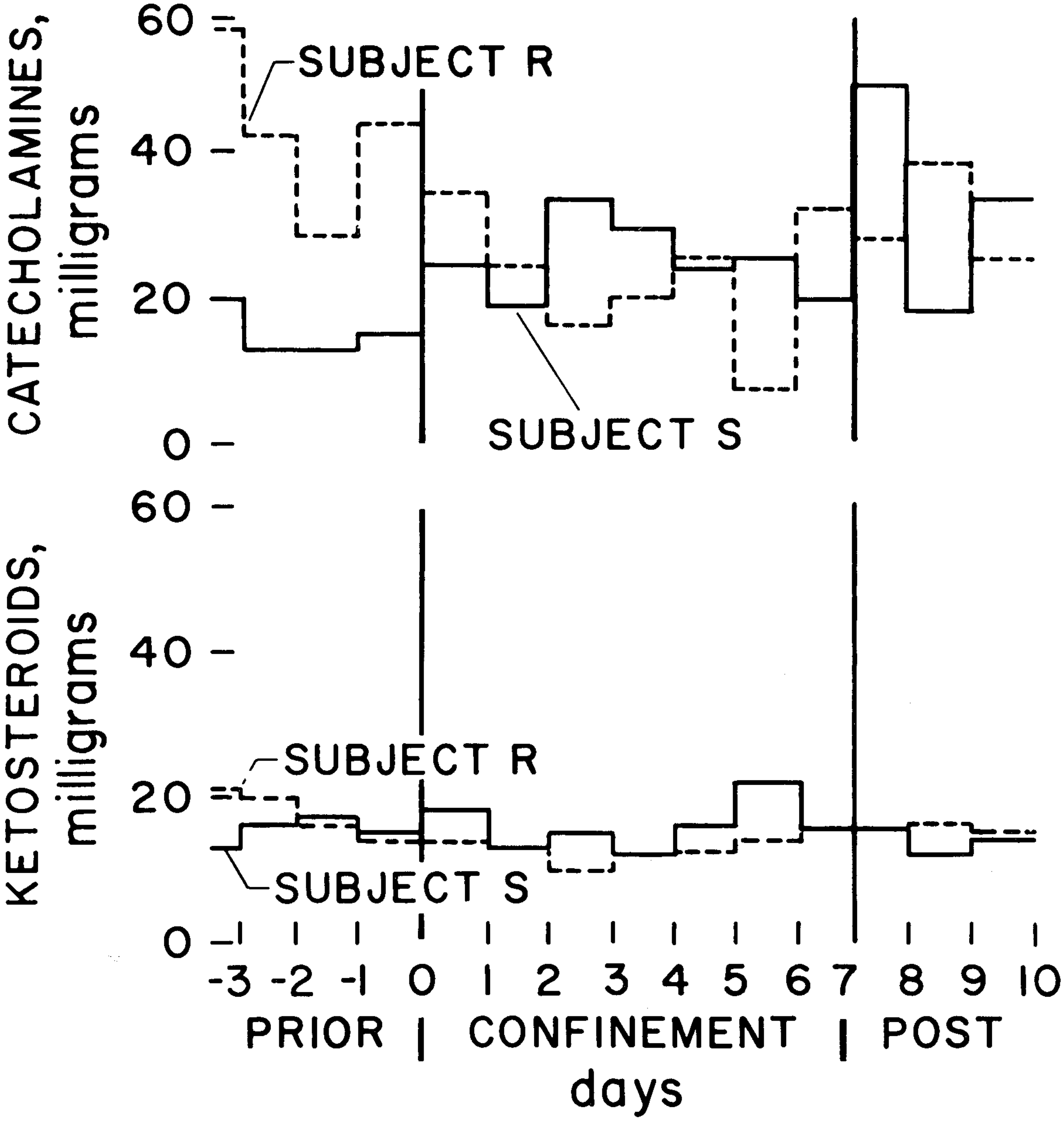


Figure 3. Urine catecholamines and ketosteroids for both subjects.

Source: Rathert et al. (Ref. 82).

Thus, it would appear that where confinement is marked, energy requirements are considerably reduced, perhaps even below bed-rest requirements; although the situation is complicated by food acceptability. It would furthermore appear that the dietary demand is less even than the expected requirement. A reduced intake in the presence of an ad. lib. diet would suggest either that confinement has a specific depressant effect on appetite, or that the dietary demand meets the requirement. In the latter case, any weight loss that occurs cannot be dietary in origin.

In the larger simulators, where more free space is available, weight change seems more directly related to food intake. Thus, in the General Electric study [33] (1964) the available dietary intake was 2800 kilocalories. The average actual intake was 2550 kilocalories, a figure which includes the intake of one subject who was deliberately restricting his diet in order to lose weight. On this diet the other three members maintained a positive weight balance throughout the 30 day trip. In the Martin Baltimore study (Grodsky and Bryant, [38] 1962), however, dietary intake on flights one and two was only 1800 kilocalories and average weight loss of $1\frac{1}{2}$ lbs. was noted. In flight three, the diet was further reduced to 1500 kilocalories and resulted in weight loss varying from $6\frac{1}{2}$ to 9 lbs. per man over a 7 day period.

Stress Manifestations.

Physiological manifestations of stress are associated with increases in the excretion of end products of glucocorticosteroids, increases in catecholamine production, changes in the skin sweating pattern reflected in altered skin resistance or conductance, and changes in the proportionate distribution of blood cells. Consideration of the psychological effects of confinement has indicated that it can be a stressful situation, and physiological studies have shown significant alterations in the above noted parameters.

Excretion of ketosteroids, as glucocorticosteroid end products, has been examined by several groups along with the excretion of catecholamines. Excretion of these substances, however, varies considerably with the individual, as is well illustrated in the NASA Ames study (Rathert et al. [82] 1964) where the two subjects concerned in this 7 day study were of considerably different

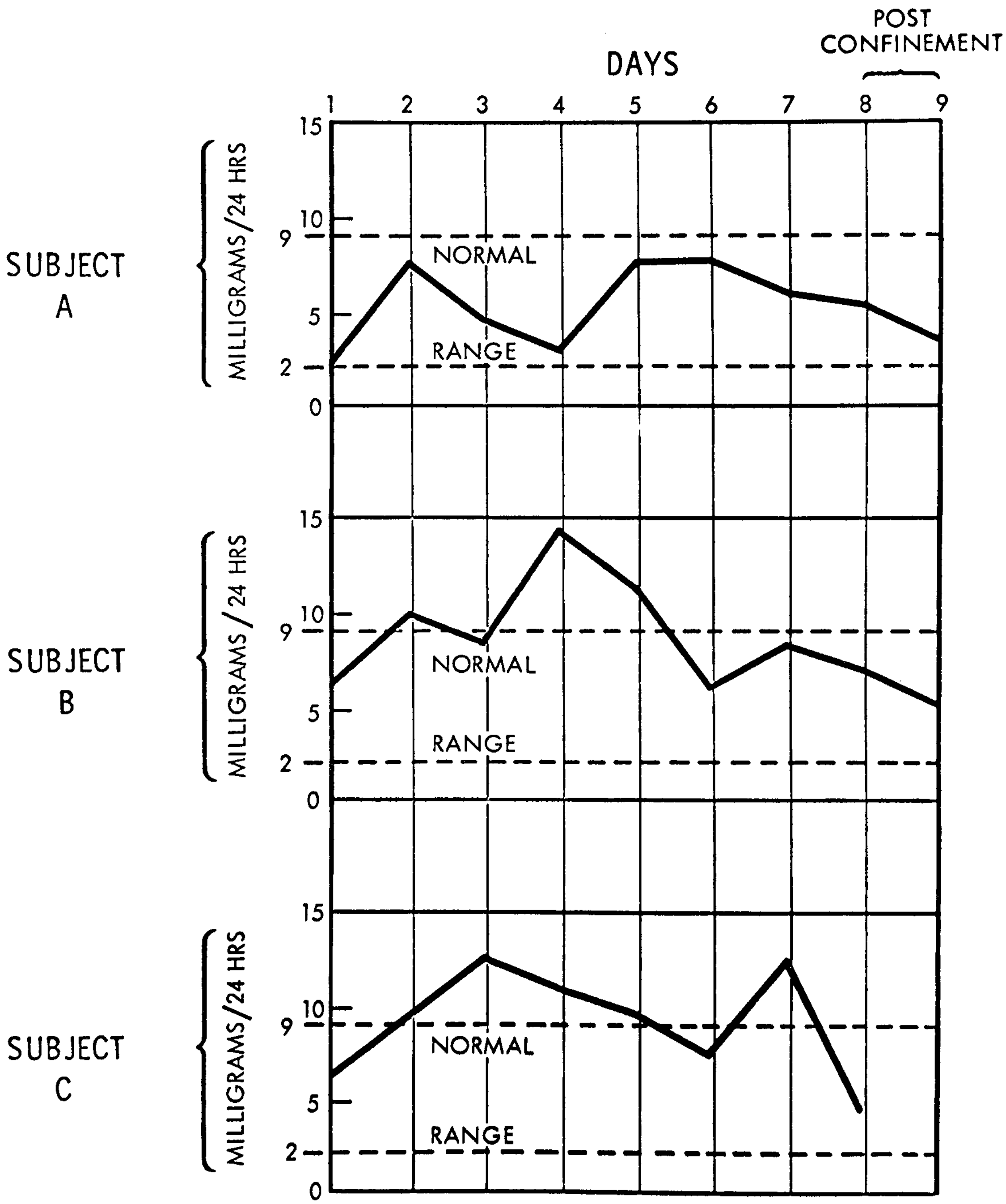


Figure 4. 17-Hydroxycorticosteroid Excretion in Urine per 24 hour Period.

Source: Celentano et al. (Ref. 14).

temperaments. Results are illustrated in Figure 3 which shows a relatively higher pre-confinement excretion of both catecholamines and ketosteroids in subject R which reduces as he presumably settles into the study and starts to rise again towards the end of the confinement. Zuckerman [104] (1964), reviewing isolation studies, points out that confinement of two hours or less does not present measurable biochemical indications of stress.

In their 7 day study, Celentano et al. [14] (1962) found the results indicated in Figure 4 and, as can be seen, both subjects B & C surpassed the normal range on more than one occasion. On day four, where the excretion is particularly high, the subjects considered terminating the study. The authors point out that if the post-confinement levels on day 8 and 9 are actually the normal levels for the subjects then the results assume even more significance.

The variation in excretion associated with particularly distressing episodes was also observed by Hanna [41] (1962) and Tiller and Figur [91] (1959) with respect to catecholamine excretion. Figure 5 shows the effect on different parameters, including urinary norepinephrine production and skin conductance, of an emergency occurring on day 5. It also shows the trend in reduction of the measures before the emergency occurred. This same trend towards gradual reduction of level was noted in the Russian studies by Gorbov et al. [37] (1964). In the Martin Baltimore 7 day simulation (Grodsky and Bryant [38] 1962; Hatch et al. [45] 1964), where no significant physiological or psychological impairment was observed, the ketosteroid excretion showed no changes other than diurnal.

The day to day excretion of norepinephrine and epinephrine in the urine was measured by Tiller and Figur [91] (1959) in the six men confined for 8 days in the Navy simulator. The results are shown in Figure 6, which has been compiled from the data in their paper. Noting the normal daily excretion of norepinephrine and epinephrine to be in the range of 20 to 40 micrograms and 4 to 8 micrograms respectively (von Euler and Lundberg [25] 1954) they observe that only on day 5 did the norepinephrine values exceed normality. This they relate to the previously noted simulated emergency. By the same token the epinephrine values were exceeded throughout. According to

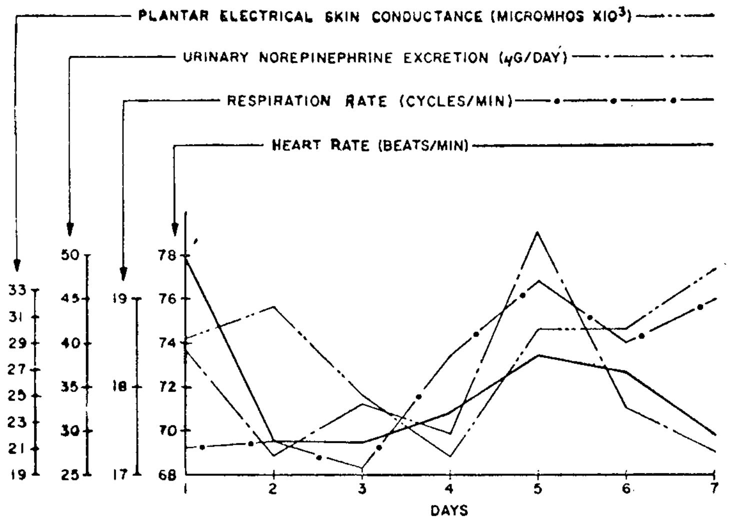


Figure 5. Comparison of mean values for all physiologic indices. (Scales have been readjusted for ease of comparison)

Source: Hanna (Ref. 41).

Funkenstein et al.[30] (1954), among others, excessive excretion of norepinephrine-like substance is associated with overt emotion, whereas excessive excretion of epinephrine is associated with covert anxiety. The increase in epinephrine excretion observed here would appear to indicate that confinement per se, on the ground in a simulator, where in fact there is no danger, is a covert anxiety-inducing situation.

The General Electric group[33] (1964) also plotted catecholamine values for their subjects. Again it was shown that the norepinephrine excretion remained within normal values except in the case of one subject immediately pre-run. On the other hand, epinephrine excretion increased markedly until the third day, at which point it began to fall off, reaching the normal range by the end of the first week of the 30 day study. This is no doubt related to adaptation to the environment.

Skin resistance, or the reciprocal, skin conductance, has been used as an indicator of stress manifestation, and is popular in psychological studies (Adams and Chiles[3] 1961; Dempsey et al.[22] 1956; Gorbov et al.[37] 1964;

Grodsky and Bryant [38] 1962; Hanna [41] 1962; Hatch et al. [45] 1964; Mallick and Ream [69] 1963; Weybrew [98] 1963). Zuckerman [104] (1964) in his review has considered the alteration in skin resistance that occurs in subjects under isolation, and points out that after a few hours isolation a decrease in skin resistance becomes manifest. In general the change follows the pattern of norepinephrine excretion, with resistance initially decreasing and conductance increasing as confinement begins, and returning towards normal, except for emergency reactions, within 6 to 8 days. This general pattern will be further examined later in considering the adaptation process. Adams and Chiles [3] (1961), in addition, commented on the diurnal variation.

Reduction in the eosinophil count may be found in stress situations. This has not, however, been a feature of confinement studies, although Faucett and Newman [26] (1953) during confinement of 22 men in a submarine for 60 days observed signficiant drops in the eosinophil count. Other than the hematocrit changes associated with loss of blood volume, hematological changes have not been noted.

Central Nervous System

There is little in the way of definitive information on changes in electroencephalographic activity resulting from pure confinement. Ruff et al. [83] (1959) describe the use of the EEG in their studies in the WADC five-man long range mission simulator, but used it primarily as an index of consciousness. Considerable work has been done by the Russians (Gorbov et al. [37] 1964) on subjects confined for 10 to 15 days in near isolation from all stimuli. Using a bipolar EEG with the additional stimulus of a periodically flashing light, they found a general decrease in the amplitude of signals and the appearance of slow diffuse rhythms which were altered by the occurrence of the light stimulus. After the light stimulus, shifts in the level and the period of the alpha waves were observed which initially lasted for short periods. As "fatigue" became more evident with progress of confinement the changes in alpha rhythm lasted progressively longer, until, towards the end of the confinement period (10 to 15 days), they became sustained. On the second day after cessation of the test, EEG records showed that when the light stimulus was stopped, the pre-confinement EEG rhythms were restored. Also, with

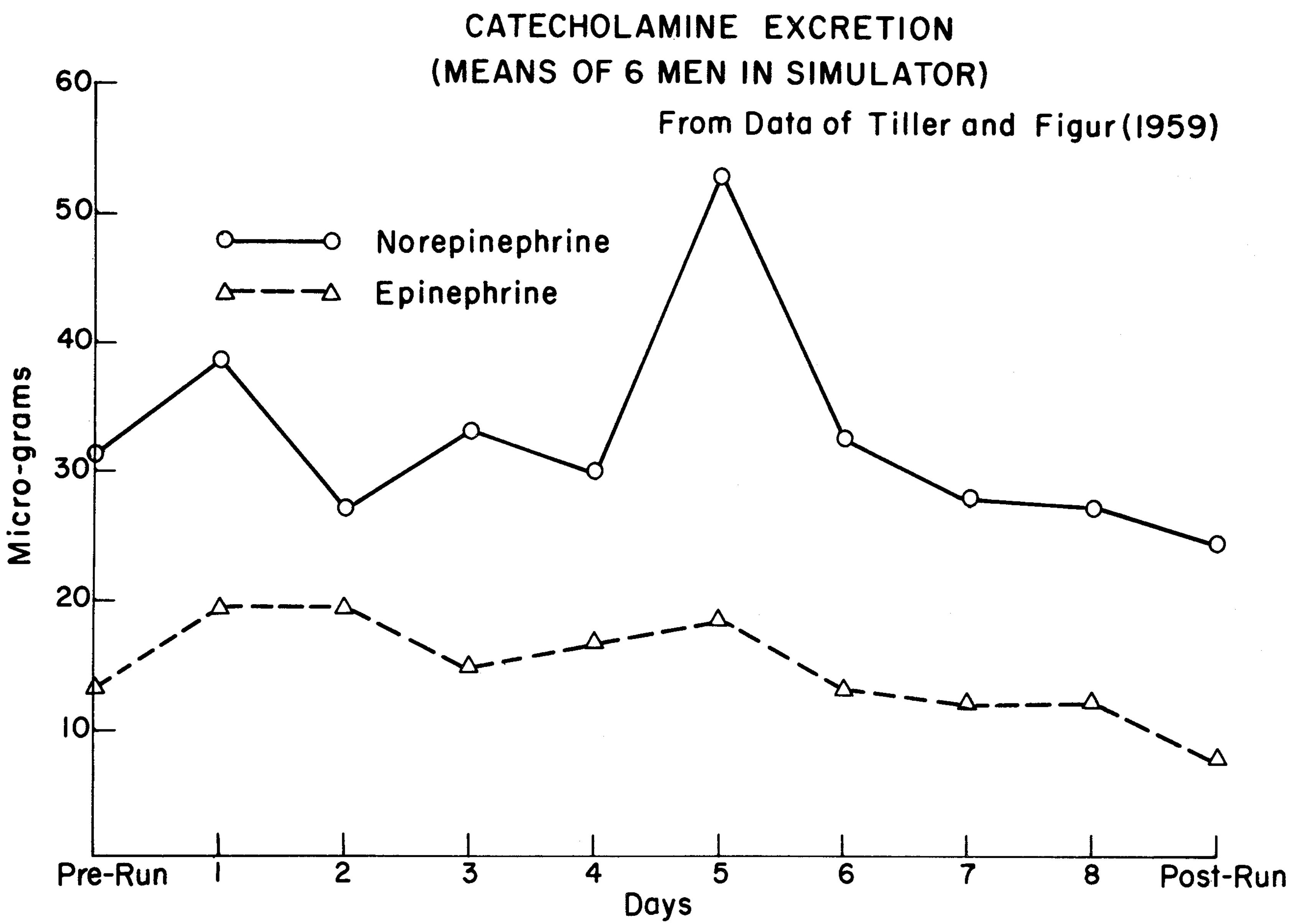


Figure 6. Catecholamine Excretion

progress of confinement, there was a general slowing of cortical activity, becoming most marked some 6 to 8 days after the onset of confinement. A similar slowing of EEG activity was found by Heron (quoted by Zuckerman [104] 1963) in six subjects exposed to four days of isolation. Zubek and his colleagues [102] (1962) also observed a progressive decrease in alpha frequencies in 15 subjects isolated for two weeks under conditions which included continuous exposure to unpatterned light through translucent goggles, and white noise masked by ear muffs. The decrease was accompanied by an increase in theta waves from the occipital lobes. The decrease in alpha frequency lasted more than seven days after cessation of the isolation. Zuckerman [104] (1964) suggests this retardation might be associated with the motivational loss of post-isolation subjects.

There is some evidence that decrease in frequency may be related to both isolation and immobility. The decrease associated with isolation is noted above. However, it also occurs in severely immobilized subjects where no attempt is made to produce deliberate perceptual isolation. Zubek and Wilgosh [103] (1963), in one of the most severe confinement studies recorded, immobilized 22 subjects individually in a seven foot "coffin" for seven days and found, in addition to impaired intellectual performance, a significant decrease in occipital lobe frequencies. Investigating this situation from another point of view, Zubek [101] (1963) compared the EEG response of two groups exposed to the same isolated conditions, with the exception that one group undertook programmed exercise, and found that the decrease in frequency that occurred was significantly less with the exercise group than with the no-exercise group, and furthermore, that a control group (non-isolated) showed a slight increase in mean frequency. Thus, while isolation is associated with decrease in EEG activity, it would appear that decreased activity may also be induced by restricted movement, and indeed relieved in part by active movement. The significance of these findings with respect to confinement in space cabins remains to be established, although the Russians have reported in their Vostok flights an increase in high frequency components occurring during the first hour, along with persistent dominant beta frequencies which were maintained for two days. The low frequency components remained at a minimum. These findings, however, probably reflect the result of combined stress rather than confinement per se.

Biochemical Studies

Besides estimations of ketosteroids and catecholamines which have been previously discussed, other aspects of biochemistry have been examined (Celentano et al. [14] 1962; Dempsey et al. [22] 1956; General Electric [33] 1964; Hendler and Mancinelli [50] 1958; Lamb et al. [63] 1964a; Morgan et al. [74] 1961; Rathert et al. [82] 1964). These have included urinalysis, measurements of urine and serum electrolytes (sodium, potassium, calcium), fecal calcium, blood urea nitrogen, blood and urine creatine, nitrogen balance, blood lipids, blood proteins, and protein bound iodine. While the majority of measures showed no significant or characteristic change, particular attention is to be directed to one subject in the NASA Ames study (Rathert et al. [82] 1964) in whom a negative calcium balance was found after 7 days of close confinement. This did not occur in the other subject in the study, nor has it been observed in other space cabin confinement studies, although it is a well-recognized accompaniment of prolonged immobilization. Changes in bone densitometry of the os calcis and a digit, regarded as indicating decalcification, have been found in the astronauts of Gemini IV, V, and VII, in comparison of films taken pre- and post-flight (NASA [78] 1966). These changes, of course, will also be influenced by the associated exposure to weightlessness.

Nitrogen balance studies (e.g., General Electric [33] 1964) indicate that despite the intake of an adequate diet (2800 kilocalories, 15% dryweight of protein) and maintenance of weight, there is a trend towards negative balance indicative of tissue protein breakdown. Figure 7 indicates the cumulative nitrogen balance over a 30 day confinement period and shows that while one subject maintained a positive balance the other three declined. The data include one subject (the lowest curve) who was on a self-imposed obesity diet.

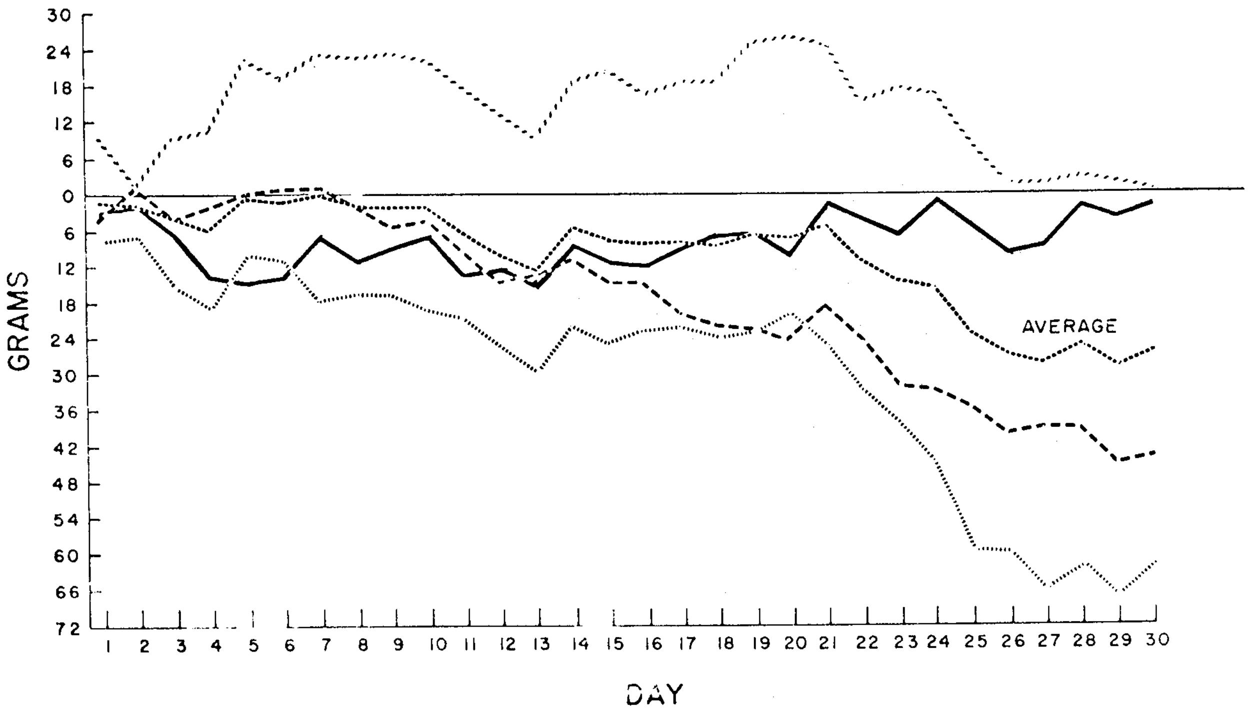


Figure 7. Cumulative Nitrogen Balance
Source: General Electric (Ref. 33).

In lipid studies (Lamb et al.[63] 1964a), an interesting association developed relating the age of the subject, weight change, and serum cholesterol level in subjects in the SAM simulator. In all four subjects with a post-confinement increase in serum cholesterol the subjects were 19 years of age or less, and demonstrated a weight gain during their 30 day confinement. In 10 subjects with weight loss, who also had cholesterol estimations, nine demonstrated a decrease in serum cholesterol level. How much this represents a difference in dietary intake associated with age is debatable.

Respiratory Studies

Respiratory studies have been undertaken by several groups, although largely with the intent of determining the response to the abnormal atmospheres commonly used in simulators rather than to confinement per se.

It is difficult in consequence to define any changes that are due to confinement alone. Respiration rate, however, tends to remain largely within normal limits, although Hanna [41] (1962) observed a trend in the 7-day Navy studies, which were conducted at sea level with an oxygen regeneration system, towards a drop in rate with the first few days. (See Figure 5, page 63). This was also noted in Adams and Chiles [3] (1961) in their studies of work-rest cycles and by Lebedinskiy et al. [65] (1964) in the Russian studies. This finding, however, is not confirmed where the atmosphere is other than sea level equivalent. For example, in the SAM one-man studies (Steinkamp et al. [88] 1959) at 18,000 feet simulated altitude with an oxygen partial pressure of 159 mm Hg, respiration rates were maintained fairly steadily throughout the 7-day exposures. Diurnal variations in respiratory rate have also been observed (Adams and Chiles [3] 1961).

Pulmonary function studies, again undertaken in connection with cabin atmospheres during confinement experiments, show a slight decrease in vital capacity (Morgan et al. [74] 1961). This is most marked during the first few days (General Electric [33] 1964). An increase in maximum breathing capacity(MBC) was observed in the SAM studies (Morgan et al. [74] 1964) directly related to altitude. The MBC at 33,000 feet (100% O_2)was considerably greater than that at 18,000 feet. This perhaps explains why in the G.E. studies [33] (1964) conducted at 18,000 feet no obvious change was observed in the MBC, since increase in MBC is no doubt related to reduced air density and friction. Other unexplainable contradictions exist, however, in that the timed vital capacity in the SAM studies was increased at altitude whereas in the G.E. studies it was reduced. Increase in tidal volume with altitude was also noted in the SAM studies. Pulmonary function studies conducted by the Douglas group (Havens [47] 1965) in a 50/50 oxygen/nitrogen atmosphere were unremarkable.

From the somewhat meager data, then, it would appear that under conditions of confinement, exclusive of the effects of altitude, there is a trend towards reduction in respiratory rate, and no doubt in respiratory function, although the latter has not been definitely demonstrated in sea level confinement. Respiratory function also shows diurnal variations.

Adaptation to Confinement

From consideration of the physiological and psychological findings, the question arises as to whether adaptation to confinement takes place. It would appear that if the confinement is sufficiently severe there is an initial stress reaction, manifested by findings such as raised heart rate, respiration rate, systolic blood pressure, excretion of 17-ketosteroids and catecholamines, reduced skin resistance, etc., which last for a few days, before beginning a progressive reduction which leads inter alia to cardiovascular deconditioning and general physiological "deactivation." This progress may be disturbed by stressful episodes. The Russians, who have maintained subjects in confinement for up to 120 days (Lebedinskiy et al. [65] 1964) have examined this process of adaptation. During 60 day tests they observed over the first 10 to 15 days changes "....which on the whole could be characterized as the initial reaction to the change in life conditions. This reaction is related to the process of adaptation of the organism to a new functional level, which corresponds to a certain extent to the new conditions. Towards the end of this period, there occurs a change in the regulatory mechanisms of the functions of blood circulation and respiration.." These changes have been documented in the respective sections.

Lebedinskiy et al. [65] (1964) go on to argue that these and other changes represent an alteration in the "habitual sterotype"----a resetting of the threshold---most probably as a result of a change in functional activity of the CNS, as manifested by development of an inhibiting process in the cerebral cortex (decrease of light sensitivity on EEG, slowing of EEG activity, etc.,), which, at least in isolation situations, is associated with a reduction in the totality of stimulation. Thus, after the initial stress reaction, there is a normalization or even reduction of many functions, accompanied by a more ready fatiguability. If the unfavorable environment should continue, the new "habitual sterotype" level eventually becomes inadequate and towards the end of 60 days further symptoms become manifest. Lebedinskiy terms these symptoms "asthenization" and characterizes them as reduced working capacity, enhanced fatiguability, change in sleep function, weakening of immunal activity, reduction of the functional potential of the cardiovascular system (?severe deconditioning), decrease in work efficiency and "very specific changes in the dynamics of cortical processes." This is rather akin to the pattern described by Ruff et al. [83] (1959).

In addition, on cessation of prolonged confinement and transition to normal life there is an "emergence reaction" characterized by deepening of the asthenia, which may last for as long as two months after a 60 day test. Lebedinskiy states: "The mechanism of creation of the emergence reaction apparently consists of the fact that as a result of prolonged human confinement in the chamber, there is formed a type of stable and fixed stereotype whose breakdown and replacement takes place with more difficulty than does the adaptation to the conditions created in the sealed chamber because the adaptive capacities of the organism themselves have been weakened by the prolonged influence of unfavorable factors in the course of the tests."

The Russian studies, however, showed further that if there is a gradual transition into confinement, and if the confined environment is made to resemble the exterior environment as much as possible by improvement in physical conditions, reduction of monotony, exercise, varied diet, etc., carried through into the emergence period, then the less pronounced will be the ultimate reaction. This response has been shown in experiments involving confinement of 120 days duration.

In an extension of his studies in armored personnel carriers, another aspect of adaptation to confinement has been demonstrated by Hicks [58] (1964). He examined post-confinement, the effects of repeatedly confining a single group of subjects for a 12 hour period on each of five successive days, measuring the effects on equilibrium, stamina, gross motor coordination, and marksmanship. As compared with pre-confinement control measures, statistically significant losses occurred in all areas after the initial confinement period. Subsequent confinements showed progressively smaller decrements until by the end of the 5th day of exposure the subjects performed at the pre-confinement level. The implications with respect to training are obvious.

Thus, if these interpretations are accepted, there is a limited adaptation to confinement, after the initial stress reaction, which takes place within 5 to 15 days of onset and is achieved by formation of a new habitual stereotype. This latter, however, is unstable, and if the environmental conditions are maintained it will disintegrate and lead to the development of a deepening asthenia which is more stable and will persist for a prolonged period after confinement. The extent and depth of the asthenia can be minimized by gradual transition to full confinement and reduction of its austerity.

Although biochemical evidence is lacking for long duration exposure, the picture shows certain parallels to the pattern of the General Adaptation Syndrome described by Selye [86] (1950). The General Adaptation Syndrome is characterized by a preliminary Alarm Reaction manifested initially by "shock," and rapidly followed by "countershock," which imperceptibly merges into a Stage of Resistance, in which there is an increased resistance to the particular stressor agent or agents involved and decreased resistance to others. Resistance, however, cannot be maintained indefinitely and a Stage of Exhaustion develops in which the resistance wears out.

The Stage of Exhaustion is characterized by changes in hormonal pattern, changes in the structure of body organs, and, according to Selye, a tendency towards the development of various disorders such as gastric ulcers, hypertension, etc., which arise from maladaptation. The nature of the resulting disorders depends upon conditioning of the so-called target organ by outside factors such as heredity, diet, previous exposure, or the specific actions, as opposed to the non-specific, of the stress itself.

While there is controversy over Selye's interpretations, particularly with relationship to the development of clinical syndromes, the possibility of their occurrence in prolonged confinement must be borne in mind.

TOLERANCE OF CONFINEMENT

In the previous sections the psychological and physiological response to confinement have been examined. The nature and extent of these responses determines the tolerance of confinement. Tolerance in this context represents not only the ability of an individual to bear the subjective discomforts, but is an estimate of the extent to which his function is disturbed. Emphasis is placed on the degree of impairment which will not interfere with satisfactory completion of his task.

Excluding three or four studies in which perceptual isolation in darkness and reduced noise was a primary feature, Table 6 selects pertinent details from the reports outlined in Table 1, and to each of these studies applies an estimate of the degree of psychological and physiological impairment demonstrated by the subject or subjects participating, as indicated by examination or test before, during, and after the confinement. The extent of impairment is estimated on the basis of a three point scale:

1. No impairment
2. Detectable impairment
3. Marked impairment

The factors evaluated in estimating the degree of impairment include the reported level of performance of intellectual, perceptual, manual, and coordinated tasks, the response to psychological testing, the subjective comments of the participants, the nature and extent of physiological change, the nature and extent of behavioral change and the nature and extent of somatic complaints. The occurrence of post-confinement reactions, for example, from cardiovascular deconditioning is included in the evaluation. Marked impairment is considered to be that which gives rise to manifest psychophysiological change during or after the confinement, or that which could prejudice the safety or successful outcome of a mission. Detectable impairment is considered to occur in a situation which is tolerable, but is accompanied by measurable evidence of disturbance which could reduce proficiency. The classification of no impairment includes those situations where some disturbance of homeostasis or comfort may exist, without interference with proficiency.

TABLE 6

Extent of impairment resulting from confinement

Type of Study	Operational Conditions	Volume per Man (cu. ft.)	Duration (days)	Impairment Psych	Impairment Physio
Simulator Single	SAM one-man	47	7	3	2
	SAM one-man	47	1 1/2	2	1
	Vostok one-man	90	?1	1	1
Simulator Multi	Lockheed-Georgia OPN-360	183 - 250	15	2	2
	Lockheed-Georgia HOPE-II	187	15	2	2
	HOPE-III	110	30	2	2
	HOPE-IV & V	110	12	2	2
	HOPE-VI & VII	187	12	2	2
	Navy ACEL	75	7	2	2
	Navy ACEL	75	8	2	2
	N.A.A. conical	67	7	2	2
	N.A.A. cylindrical	375	7	1	1
	N.A.A. disc	800	4	1	1
	SAM 2-man	106	14	2	2
	SAM 2-man	106	17	2	2

Continued on next page

TABLE 6 (Continued)

Extent of impairment resulting from confinement

Type of Study	Operational Conditions	Volume per Man (cu. ft.)	Duration (days)	Impairment Psych	Impairment Physio
Simulator Multi	SAM 2-man	106	30	2	2
	Republic	211	14	1	1
	Douglas	250	30	1	1
	GE	215	30	1	1
	Martin Baltimore	133	3	1	1
	Martin Baltimore	133	7	1	1
	NASA Ames	61.5	7	2	2
	WADC long range	140	5	2	2
Confined Chamber Single	U. of Maryland	1368	152	3	3
	U. of Georgia	65	3	2	2
	U. of Georgia	52	3	3	2
	U. of Georgia	52	4	3	2
	U. of Georgia	52	14	3	2
	U. of Georgia	39	7	3	2
	USNRDL	117	14	2	2
	USNRDL	117	5	2	2
	Lockheed Georgia	125	4	1	1

Continued on next page.

TABLE 6 (Continued)

Extent of impairment resulting from confinement

Type of Study	Operational Conditions	Volume per Man (cu. ft.)	Duration (days)	Impairment Psych	Impairment Physio
Confined Chamber Single	"Coffin"	28	7	3	3
Cockpit	F-84	<30	2 1/3	2	2
	WADD capsule	27. 5	2	2	1
Vehicle	APC M59	30	1/6	1	1
	APC M113	23. 3	1/3	2	2
	APC M113	28	1/2	2	2
	APC M113	25. 5	1	3	?
	APC M113	25. 5	1	3	3
Submarine	Nautilus	1600	11	1	1
	Seawolf	570	60	1	1
	Nautilus	570	4	1	1
	Triton	570	83	1	1
Chair	SAM	<25	4	1	3

Continued on next page.

TABLE 6 (Continued)

Extent of impairment resulting from confinement

Type of Study	Operational Conditions	Volume per Man (cu. ft.)	Durations (days)	Impairment	
				Psych	Physio
Bed	Lankerau	<25	45	1	3
	SAM	<25	28	1	3
	SAM	<25	14	1	3
Spacecraft	MA-6	47	1/3	1	1
	MA-7, 8	47	1/2	1	2
	MA-9	47	1 1/2	1	2
	Vostok I	90	1/2	1	1
	Vostok II	90	>1 day	1	2
	Gemini III	40	1/5 day	1	1
	Gemini IV	40	4 days	1	2
	Gemini V	40	8 days	1	2
	Gemini VI	40	1 day	1	1
	Gemini VII	40	14 days	1	2

It is appreciated that a rating scale of this nature is open to criticism as a subjective classification. However, it is considered that the distinctions between grades are sufficiently obvious as to permit assignments that will meet with minimum argument. Because of the wide variety of experience examined, with many intruding variables, it is considered inadvisable to use a more quantitative scale.

It will be noted that this Table does not include studies of "sensory deprivation," perceptual isolation, or confinement studies where elements of perceptual isolation were more than mildly incidental. Hence it does not include water immersion studies, studies in darkened and acoustically insulated rooms, studies where unpatterned light and white noise distorted the environmental input, etc.. The reports selected are those in which confinement was paramount over perceptual isolation, although inevitably some of the one- or even two-man studies contained perceptual isolation factors.

Where several experiments have been carried out for the same duration with different or the same subjects within the same device, for example, the SAM one-man space cabin, the impairment ratings represent the general response in the entire group of experiments. Where factors have been changed, such as a different number of subjects and consequently a smaller available volume, or a different duration, the experiments are rated separately. Variations in environmental conditions, such as differing altitudes, different temperature and humidity levels, are not specifically accounted for in the Table. Those situations in which these factors may have a bearing are discussed later in connection with establishing tolerance levels.

In a few cases, particularly in some of the Russian work, sufficient detail is not available to allow inclusion of the data in the Table. It should also be noted that some of the volume data are calculations which do not necessarily take full account of obstructed free space, although this is allowed for wherever possible.

The data from this Table have been extracted and are plotted in Figure 8 which illustrates the degree of impairment found when confined within a

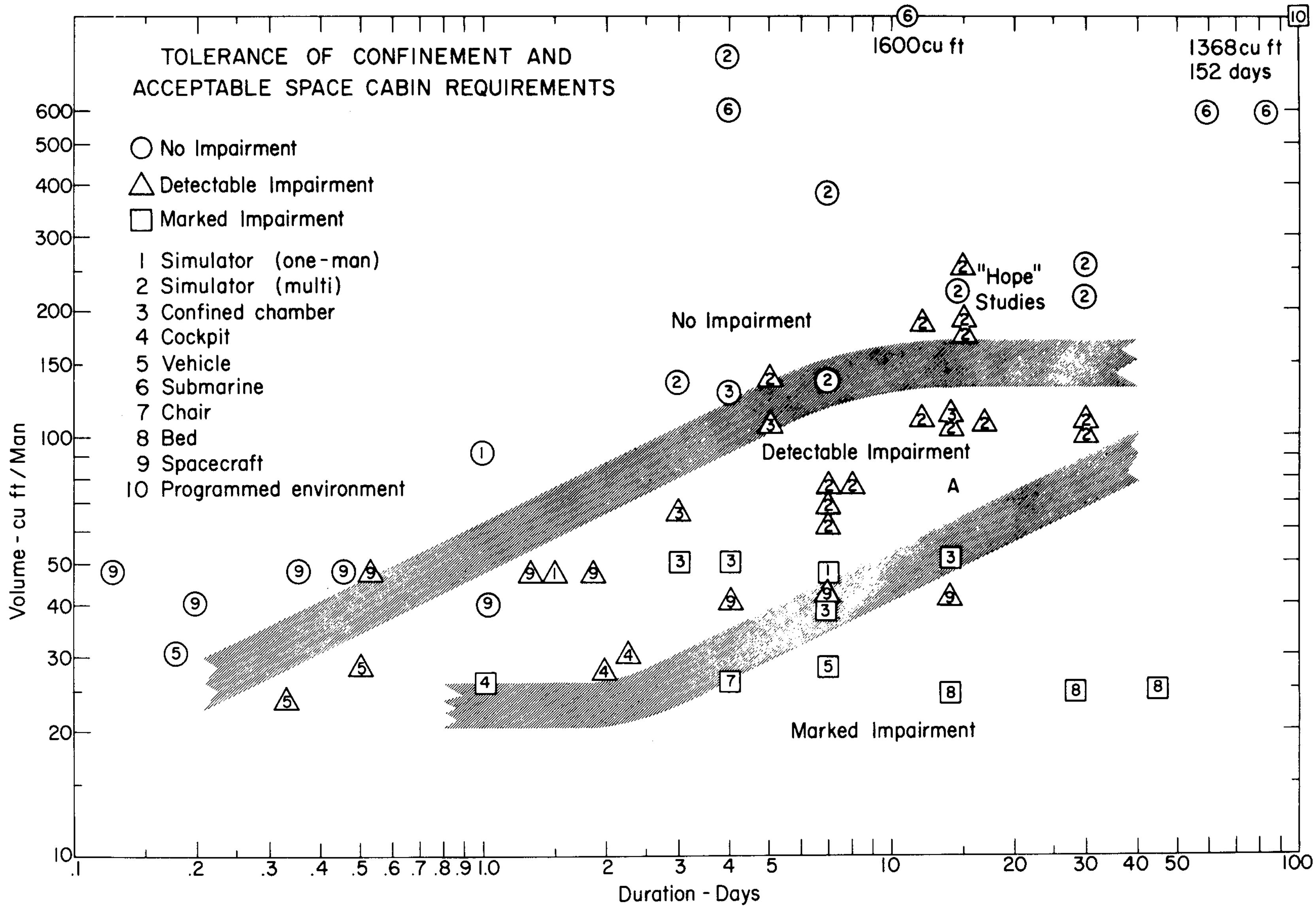


Figure 8. Tolerance of Confinement and Acceptable Space Cabin Requirements.

given volume for a given duration. The abscissa is in terms of duration, the ordinate in terms of volume per man; extent of impairment is indicated by one of three symbols, while the nature of the device within which the confinement takes place is noted by a number within the symbol. A log-log scale is used for convenience only.

It will be noted that all the experiments in which impairment has been classified as none lie above the upper line with the exception of one, the Gemini VI-A; the majority of those graded as "detectable impairment" lie between the upper and lower line; and the majority of those considered "marked" impairment lie on or below the lower line. The exceptions will be discussed.

Thus, although the data are meager, and perhaps the position of the lines could be in dispute, three zones of impairment can be defined in terms of duration of confinement and available volume per man. These are indicated in the figure. The rationale for the slopes of the curves will be discussed later.

Certain exceptions have been referred to. Notable among these are some of the "HOPE" studies, which, although classified as giving rise to moderate impairment, will be observed to lie in the no impairment zone. It will be remembered that the primary aim of the "HOPE" studies was investigation of the effects of different work-rest schedules, including in some cases prolonged periods of work in confinement without sleep. It is considered that the effects of severe work-rest schedules contributed towards the final impairment and had this not been the case, no significant impairment would have been observed. Located among the group of "HOPE" studies is Helvey's Republic study [49] (1962) in which slight impairment was observed probably attributable to oxygen toxicity.

One other study lies in the no impairment zone although severe impairment was encountered. This is the University of Maryland programmed environment study (Findley et al. [27] 1963) previously discussed. Since the circumstances in this case were far from simple confinement,it is considered that this finding does not affect the validity of the zoning.

In the moderate impairment zone, two studies may be noted in which severe impairment was found. These refer to some of the University of

Georgia shelter confinement studies [34] (1962). In these, environmental factors other than confinement were probably of significance equal to or even greater than the confinement itself. These factors included extremes of discomfort, temperature, humidity, diet, and living conditions, which apparently produced considerably more disturbance in subjects and aroused more unfavorable comment than did the severely reduced space.

Particular attention must be directed to the Gemini series of missions, which despite some evidence of impairment, have clearly shown man's ability to perform successfully in space under restrictive conditions that can only be classed as extreme. Special reference must be made to the Gemini VII, 14-day mission, in which, as can be seen from Figure 8, only "detectable" impairment was registered, although the combination of 40 cubic feet per man for a 14-day duration, would by rights place it in the "marked impairment" zone. Since the astronauts successfully completed their mission with relatively little problem and recovered their baseline physiological state within a day or two post-flight, the impairment cannot be considered sufficient to prejudice the safety or successful outcome of the mission. At the same time considerable impairment was demonstrated, despite enthusiastic reports of the mission. This was most evident in the tilt-table response post-flight, where for example one astronaut had a syncopal response at 11 minutes of the programmed 15 minute tilt, and where baseline values did not return until 50 hours post-flight. It was also observed in loss of work tolerance, loss of blood cell mass, electrolyte changes, increase in white blood cells, and some loss of calcium. Thus, while weightlessness no doubt relieved some of the problems, one might well speculate that it was largely the state of fitness, dedication, and experience of the astronauts that influenced the final outcome. The duration and extent of the restriction could not normally be considered acceptable.

Factors Modifying Tolerance

Discussion of these exceptions draws attention to the fact that there are various factors other than the volume and duration of confinement which modify the tolerance. In a study involving more than 100 separate confinement episodes, Ruff, Levy and Thaler [83] (1959) isolated a group of factors which were of considerable significance in modifying tolerance of confinement. The first category was related to the circumstances surrounding the confinement and the second to factors within the subject, such as personality type, motivation, educational and experimental background. The third category was concerned with the sensory input, quantity, modality and pattern, while the fourth related to the extent of enclosure or restraint. The degree of intercommunication was a fifth factor, while the extent of "aloneness" provided a sixth factor. Four aspects of time duration occupied a seventh category, namely, duration of isolation, degree of subjects control over duration, subject's knowledge of expected duration and the presence or absence of methods to measure time. The final category observed was the extent to which the subject was permitted or expected to undertake activities, and the nature of these activities. Some of these factors have already been examined in the course of discussion and some demand closer attention.

Motivation and experience: Of the personal variables which influence the response to confinement, there is little doubt that motivation, backed by experience, is one of the most significant factors in maintaining tolerance of confinement. Nearly all investigators engaged in space cabin confinement studies have commented on the importance of motivation in maintaining a high level of performance under adverse conditions. At the same time there has been little in the way of deliberate study of motivation. Comments have been largely the result of incidental observations. A case in point arises in the "OPN-360 study" (Adams and Chiles [3] 1961). In this study, where crews of similar experience were confined for 15 days on a 4:2 work schedule, one crew was a true volunteer crew whereas, by chance, the other crew had been recalled from leave to participate in the experiment. Despite the fact that each crew had similar treatment, between-group differences in levels and trends of performance occurred, which would appear to be related to the difference in motivation.

Similarly, in the SAM one-man simulator (Steinkamp et al. [88] 1959; Hauty [46] 1964) the most severe reactions were with relatively untrained and doubtfully motivated subjects. Where the subjects were pilots with appropriate background and experience the disturbance was much less. Adverse reactions could still occur, but with motivation and experience the subjects could adjust to them and maintain reasonable performance. Even the hostility engendered by the environment may act to maintain motivation. Gerathewohl [35] (1959) describes one subject in the one-man simulator who in effect was determined to demonstrate he would not be beaten, and also two subjects in the two-man capsule, who despite the adverse conditions, lack of appetite, excessive sweating, insomnia, irritability, and loss of weight, virtually entered into a competition in their respective performance tasks.

In another type of study, not directly related to motivation but providing indirect confirmation, Peters et al. [81] (1963) examined the unusual hypothesis that undue sensitivity to pain would correlate with ability to endure "sensory deprivation." Various standard pain tests were given to subjects who were then exposed to confinement in conditions of low level white noise and unpatterned light for as long as they could endure it. In point of fact, the hypothesis was not proved and, indeed, the opposite, and the intuitively more reasonable, finding was shown, namely, that a correlation existed between ability to endure pain and ability to endure confinement.

As Levy et al. [66] (1959) point out, there is no doubt that the response to isolation varies with individuals. Schizoid subjects find it particularly stressful; passive-dependent individuals seldom find short periods stressful although they will complain of boredom and physical discomfort. Compulsive subjects expend great effort attempting to structure the situation around tangible bits of reality. To the strongly motivated subject, however, and this is repeatedly emphasized, it is another task that has to be done and will be mastered, if at all possible, with the minimum disruption.

The Ambient Environment: The nature of the environment within the confined chamber can significantly effect the response of the confinee, as has already been mentioned in respect of the extent of perceptual and social isolation to which a subject is exposed. At the same time, atmospheric pressure, and gaseous composition will alter respiratory physiologic response (Morgan et al. [74] 1961), while the occurrence of unexpected toxic contamination was sufficient to cause abortion of a Boeing study (Lowry and Konecci [67] 1963) and has caused alarm during a recent study conducted by the Douglas Aircraft Company (Havens [47] 1965). The effects of excessive humidity, temperature, and the absence of creature comforts, contributed markedly towards the severity of subjective response in the University of Georgia studies [34] (1963), amounting in one of them almost to frank heat prostration.

The environment, however, need not be reduced in stimulus content, physically uncomfortable, nor physiologically stressful to produce a deleterious response, as was clearly shown, although with only one subject, in the programmed environment study (Findley et al. [27] 1963). In this situation, despite adequate space, mobility, comfort, and recreation, the sheer rigidity of circumstances and inevitability of predicted action was such as to produce manifest psychological disturbance and eventual defection of the subject.

Activities and Tasks During Confinement: Regardless of the environment, there is little doubt that the requirement to undertake certain activities and tasks, and the nature of those that have to be undertaken, influence the resulting response of the subject or subjects. Perceptual isolation studies have clearly shown what happens under conditions of reduced stimulus and inactivity. Task performance and activity, however, have to be meaningful before any favorable influence can be observed, and perhaps even somewhat demanding. Hawkins and Hauty [48] (1959) in discussing the response of subjects in the SAM simulators, where some of the tasks were rather artificial, noted that the work problems became boring, and when fatigued (or bored) the subjects found it difficult to keep from dozing. Similarly, the subjects in the NASA Ames study (Rathert et al. [82] 1964) commented on the "puerility" of at least one of the tasks and agreed on the "enjoyability" of a relatively complex navigational task. Grodsky and Bryant [38] (1962) made a point of using in their study dynamic performance tasks corresponding to different phases of flight control, and employed realistic displays of system and navigation information , and realistic control functions. They attribute much of the satisfactory performance of their subjects to this concept. In contrast, Hanna and Gaito [43] (1960) attribute poor performance in some of their tasks in the Navy simulator to the fact that the requirements were too simple and monotonous to maintain the interest. The significance of these comments on the design of tasks for actual spacecraft is obvious.

Christensen [17] (1963) emphasized this point and notes that although the crew will be highly motivated and will have had previous experience in difficult and even hazardous tasks, elements of boredom will still occur, perhaps because of thorough knowledge of the various tasks. He states, "The real challenge will be to design a system that will require and will use the crew members in essential jobs that are challenging enough to prevent monotony and boredom, yet sufficiently below their maximum level of capability to allow for possible performance deterioration or for emergencies.....Jobs should be designed so that the majority of a man's waking hours, other than the time required for personal necessities and short rest periods, is filled. But the jobs must not entail the performance of sham tasks that are included simply to keep the crew busy. This would be degrading and repulsive to the type of men who will participate in the mission."

Knowledge of Duration: The influence on a subject of the knowledge of duration of his confinement has been briefly referred to. Characteristically, a spurt in performance and a rise in "physiological activation" occurs towards the last day of confinement, while there is also a characteristic rise in morale at the mid-point of a known confinement period (Alluisi et al. [5] 1963). In their analysis of psychological effects, Levy et al. [66] (1959) point out firstly, although not entirely accurately, that the longer the isolation lasts the more stressful it becomes, and, secondly, if a subject knows the planned duration of an experiment in advance the isolation is easier to tolerate.

The effect of knowledge of duration is even more dramatically observed in physiological findings. Lebedinskiy et al. [65] (1964) describing the Russian studies notes that EEG changes during experiments of a known 10-day duration were considerably more pronounced than during the first 10-days of a two-month experiment, while during the first month of a four month experiment the EEG of the subjects was more stable than it had been in the pre-confinement studies. It is doubtful, however, whether useful advantage can be taken of this factor in operational conditions, although Alluisi et al. [5] (1963) in a 30-day study allowed their subjects to believe the duration of confinement would actually be 40 days.

Exercise and Physical Fitness: There is little doubt that reduced physical exercise necessitated by close confinement is a significant factor contributing to the cardiovascular deconditioning that can occur (Lamb et al. [63] 1964a). It is not clear, however, how well an active program of physical exercise will prevent deconditioning, and how much exercise of what type is required under conditions of space cabin confinement. As illustrations, subjects in the SAM simulators had no organized exercise while in close confinement and developed fairly marked cardiovascular deconditioning (Lamb et al. [63] 1964a); subjects in the NASA Ames study, slightly less confined, undertook mild physical exercise of the push-up variety, and showed ...."physiological deterioration of the same kind as that to be expected from a week's confinement to bed, but less extensive." In the Martin Baltimore study reported by Mallick and Ream [69] (1963) where the confinement was still less severe, the subjects underwent a preconditioning program involving swimming, tumbling, running, weight lifting and calisthenics, and continued during the seven day trip with a five minute exercise period for the first half of the mission (i.e., eight times per day) and then every alternate off-duty period. They showed no manifestations of cardiovascular deconditioning nor of back pain or leg weakness that had been encountered on previous simulations without exercise. Thus, while the increase in available volume, and consequently greater freedom of movement, is no doubt a factor in reduction of deconditioning, it is probable that specific exercise also assists, although the amount and type have yet to be determined.

Regardless of its efficacy as a prophylactic measure, exercise certainly seems advantageous in the maintenance of morale. Those subjects who have participated in exercise programs have commented favorably on them. In addition, there is good indication that organized exercise improves performance in other respects. There seems to be only one study embracing this subject and unfortunately from the confinement point of view, it involved a large, deliberate, element of perceptual isolation. In this study, Zubek [101]

(1963) undertook an experiment in which he confined, individually, 27 subjects for 7 days in a 450 cubic foot chamber, wearing translucent goggles, and ear-muffs through which constant white noise was presented. No restrictions were placed on activity, and in addition six 5 minute periods of exercise were introduced at irregular intervals each day. In comparison with another similar group who were confined without exercise, the exercise group showed impairment in only three out of 15 psychological tests, as opposed to 10 out of 15 among the non-exercise group. The tests embraced such things as arithmetic problems, numerical reasoning, abstract reasoning, verbal fluency, verbal reasoning, space visualization, digit span, rote learning, recall, recognition, cancellation, and dexterity, along with some perceptual motor tests. In addition, fewer hallucinatory phenomena and less disturbance of the EEG were observed among the exercise group.

Number of Confinees: One further question arises with respect to tolerance, and that is related to the number of subjects or crew members confined at the same time. It has already been pointed out that two individuals confined together are less likely to experience perceptual aberrations than one confined alone, and that with three or more, perceptual aberrations rarely, if ever, occur. In addition, with good leadership, social contact with other confinees in a small group can reinforce morale. As an interesting sidelight, however, in this regard, Davis et al. [21] (1961) report that when married couples were confined in separate respirator tanks within conversing distance they supported each other in their desire to quit, whereas strangers tended to compete with each other. The significance is debatable!

In larger groups, the adverse possibilities of developing cliques exist. Law [62] (1960), writing about problems in antarctic isolated communities, (and the same could apply to large spacecraft), recognized two types of cliques, the first made up of persons doing the same job, having the same personal interests, or ties, and the second made up of malcontents or those with personality problems who were forced to seek companionship with each other. Weybrew [98] (1963) has observed somewhat similar findings in submarine crews. There is little doubt that the key to prevention of such situations lies in careful selection of subjects or crew, and wise leadership. In fact, Law states categorically; "Leadership is the most important factor in unit morale and effectiveness." Although this is not the place to discuss astronaut selection and crew leadership, it is interesting to reflect that the nature of the astronaut selection program is such as to choose individuals with strong leadership qualities. While this is necessary for one-man and perhaps even two-man crews, it is possible that use of these same criteria could give rise to problems in multi-man crews.

In delineating recommended minimum volumes, another point has to be borne in mind. This concerns the number of subjects utilizing the available space and the mobility of those subjects within it. The majority of studies examined, and particularly those approaching the acceptable thresholds outlined, have involved crews of 3 or 4 men, and the space per man in these studies has been calculated by a simple process of division. Thus, in these circumstances, each man has had a certain minimum space plus an overlapping use of space not being occupied by his fellow-crew members, provided he is free to move. Consequently, when an experiment shows that for a certain multi-man crew (e. g., 3 or 4) a certain volume of space per man provides tolerable conditions for a given duration this does not necessarily mean that the same volume of space per man will be adequate for a one-man crew for the same duration. Intuitively, it would seem probable that a smaller crew would require relatively more space per man, and a larger crew would required relatively less. Unfortunately data are not available to verify this hypothesis since no comparative studies have been carried out and the available data do not lend themselves to the necessary analysis.

In summation of the factors modifying tolerance it must be noted that, while confinement, and particularly, close confinement, is a stress in itself, it is a stress which can be modified favorably or unfavorably by factors inherent within the confinement, such as restriction, immobility, and perceptual isolation, and by factors extraneous to it, such as those discussed above. Thus, the response to operational confinement cannot be considered strictly by itself; it must be examined in the light of the circumstances under which it takes place and allowance made for the modifying effect of additional factors.

VOLUME REQUIREMENTS FOR SPACECRAFT

Discussion of tolerance of confinement leads to consideration of the minimum acceptable volume requirements per man for spacecraft. Until recently, the free volume per man in operational spacecraft has been to some extent dictated by the volume left over after the necessary operational systems and supporting hardware have been installed. While this is perhaps adequate, or nearly so, for exposures of a day or so, it most certainly will not be for longer duration missions.

Determination of acceptable minimum volumes, however, is not a subject that is distinct to spacecraft. World navies, mercantile and fighting, have prescribed minima for officers and men; public health authorities have recommended maximum occupancies of rooms, hospital wards, etc.; military commands have detailed the minimum permissible space per man in barracks; and the organizers of protracted Antarctic sojourns have laid down their requirements.

Table 7, from the work of Celentano et al. [13] (1963), details the gross living area requirements provided by various authorities for their personnel. These data, however, are useful only as illustrations, since the situations to which they pertain are not comparable to those of spacecraft. Obviously, it would be ideal to provide sufficient free space that no problems related to confinement could arise. Equally obviously, because of constraints imposed by the available thrust,limited weight and volume of the total spacecraft, this is not practicable, and recommendations must be based on providing the minimum free volume compatible with maintenance of adequate performance, functional physiological integrity, and tolerable habitability.

Returning to Figure 8, it may be seen that the upper line provides a threshold of minimum acceptable volume. In other words, all points above that line may be considered acceptable. The lower line provides a threshold of unacceptable volume, that is, all points below the line are unacceptable. In between is an area of doubtful acceptability where impairment tends to increase with reduction in volume and increased duration of exposure. It will be noted that the lines are deliberately presented as wide bands to indicate that there is no hard and fast line of demarcation.

Table 7. Comparison of Gross Living Area Requirements

Organization	Gross Square Feet per Man	
IGY polar expedition	100	
Royal Navy	19	Seamen
	40	Petty officers
	60	Officers
U. S. federal prisons	48	Regular
	70	Honor
U. S. Maritime Service	16 to 30	Seamen
	20 to 30	Rated seamen
U. S. Navy		
Barracks	50	
Vessels	20	Seamen
	90 to 130	Officers
Space System - Minimum habitable recommendation	90	

Source: Celentano et al. (Ref. 13).

From the figure it will be observed that, with confinements from a few hours to about one week, to provide acceptable conditions there is a linear increase in the volume requirement per man from about 25 cubic feet to about 125 cubic feet. Thereafter, from 7 to 30 days, there is a much slower and perhaps insignificant increase from 125 cubic feet to about 150 cubic feet. It is emphasized that these numbers are approximate and are applicable only to situations in which habitability of the confined volume and general working conditions have been maximized. Some of the "HOPE" studies, for example, which lie outside this boundary, indicate as has been noted, that adverse working conditions reduce the acceptability even when the available volume is apparently adequate.

Beyond 30 days of confinement the data are too meager, to permit any extrapolation. The Russian work, as noted (Lebedinskiy et al.[65] 1964), suggests that the slope of the acceptable threshold curve remains unchanged until at least 60 days before further significant impairment occurs, but the conditions under which this work was carried out, and in particular, the free volume available are not clear. It may be that after 60 days the curve tends to sweep up again. There is no doubt, however, as has been demonstrated in submarines (Weybrew, [98] 1963), that confinement for 80 days or more with an available volume of 600 cubic feet is tolerable with little disturbance.

At the opposite end of the scale, it is a little difficult to establish the threshold between acceptability and impairment for durations of a few hours. It is very probable there is no significant impairment during confinement for an hour or two within any volume larger than body volume, provided there is adequate ventilation. From the point of view of spacecraft design, however, the question is somewhat academic, since missions of less than one day are no longer expected. For a duration of one day it would seem that the acceptability threshold is about 50 to 55 cubic feet, and in practice this has been to some extent confirmed by the Mercury missions (47 cubic feet), in which there was a little impairment which perhaps would not have occurred had the spacecraft been slightly larger.

Below one day duration, the threshold of unacceptability probably slopes back from about 25 cubic feet to meet the threshold of acceptability at about the level of body volume, but confirmatory data are not available. Between 1 and $1\frac{1}{2}$ days, there appears to be a lower cut-off at about 25 cubic feet. Thereafter there is a progressive rise in threshold with time to at least 15 days where the threshold would seem to be about 60 cubic feet. From there on, data are unavailable, but there is no reason to doubt that the threshold continues to rise until it meets the threshold of acceptability at perhaps about 60 days.

In other words, the change in slope in the <u>upper</u> threshold, occurring at about 7 to 10 days, suggests that factors other than confinement are beginning to affect the occurrence of impairment. The progressive increase in slope of the lower threshold, until it meets the upper, suggests that the lower curve is indicating the threshold of adverse effects of volume per se, and that at the point where they meet the volume is no longer the major limiting factor, and that other considerations related to duration are beginning to bear more strongly. It is interesting to observe that extrapolation of the curves suggests junction at or about a duration of 60 days, the same duration at which the Russians describe a resurgence of stress effects.

The two threshold curves outline an area in which exposure give rise to a detectable degree of impairment. It is in this area that much of the experimental and operational confinement has taken place. The 15-day Apollo lunar mission (marked on the figure with the letter "A") is seen to lie within that area, and in consequence some degree of impairment can be expected. Mention has already been made of the 14 day Gemini mission which lies outside the area.

In the light of the success to date of the Gemini missions, one might question the validity of these predictions. There is no doubt that experimental and operational studies have shown that problems arise when available volume is reduced below the limits defined above. At the same time, the Gemini series has shown so far (GT-VII) that impairment is acceptable despite severe confinement. It is probable, however, that some of the modifying factors previously discussed contributed greatly towards the success of the Gemini series. Notable among these would seem to be motivation of the crews, the overlapping use of space, and perhaps certain aspects of weightlessness itself.

It is obvious that motivation of the crews has been very high indeed, whereas in some of the experimental work, at least, the motivation has been doubtful. Overlapping use of space, as has been noted, may permit a greater effective free volume with a double or multi-man crew than the actual free volume would indicate. The question of the combined effects of weightlessness and confinement is a difficult one. There is some doubt as to how much of the expected cardiovascular deconditioning of space flight will be attributable to weightlessness and how much to confinement (Lamb et al. [63] 1964a). As has been noted, the possible synergistic effect of weightlessness and confinement might be expected to lead to even more impairment than the action of either alone. At the same time, weightlessness has some favorable attributes. Under weightlessness, mobility will be improved, while some of the discomforts of restrictive immobility, which are aggravated by the gravitational pull, will be considerably relieved. It seems intuitively reasonable, that, despite the predictions based on Figure 8, there might be a duration of combined confinement and weightlessness during which the weightlessness has an ameliorating effect, but if the duration is still further prolonged a greater impairment may occur.

Bearing these considerations in mind, and emphasizing again that acceptability of conditions depends not only on available space, but on favorable habitability and working conditions and may be modified by other factors, the requirements shown in Figure 8 can be outlined as indicated in the following table.

TABLE 8

Threshold volume requirements according to duration of mission

Duration (days)	Threshold of acceptable volume - Cubic Feet	Threshold of unacceptable volume - Cubic Feet
1	50	25
2	75	25
3	90	25
4	105	30
5	115	35
6	120	35
7	125	40
10	135	50
20	140	70
30	150	85
>60	?150	?150

Source: Fraser, 1965.

It is emphasized that these numbers are not rigid since the thresholds to which they refer are not rigid lines of demarcation but regions where one zone merges into another. Each of the numbers refers to the approximate mid-point of such zones but has been rounded to the nearest 5 cubic feet.

From these figures it may be seen that for confinement under circumstances of good habitability and working conditions for durations of 7 to 30 days for small group crews, about 125 to 150 cubic feet per man of free space would provide acceptable conditions. Severe impairment under the same conditions might be expected with a free volume of less than 40 cubic feet per man for 7 days or less than 85 cubic feet per man for 30 days.

Two other studies are available in which attempts have been made to predict volume requirements. In one of these, Celentano and his colleagues (Celentano et al.[13] 1963) utilized the hypothesis that an optimum cabin size would be one which provided sufficient space for normal semi-sedentary activities as measured by the metabolic rate of the subjects. Accepting the metabolic rate of the semi-sedentary office worker as 2800 Kcal per day they investigated the metabolic rates of subjects in each of three cabins. In the first cabin, allowing 67 cubic feet for each of the three men, the metabolic rates were found to be almost those of bed-rest (2300 Kcal per day). In the second cabin, allowing about 375 cubic feet, the energy expenditure was close to the lower limits characteristic of the sedentary worker (2550 Kcal per day). The third cabin, with 800 cubic feet for each of two men, permitted metabolic rates equivalent to those of the average semi-sedentary office worker.

On this basis, a cabin volume of 800 cubic feet per man would be optimum, and 375 cubic feet per man would be acceptable. It is considered, however, that these values are not realistic. The hypotheses is valid only in part. Certainly activity is correlated with metabolic rate, but it is very doubtful if activity potential is the criterion by which the optimum size of a cabin should be judged. Adequate levels of performance and physiological function can be maintained with relatively low activity levels, and for that matter relatively high activity levels can be maintained within relatively small volumes. Even assuming activity potential is a criterion, there does not seem to be any good reason to consider that the activity level of the office worker should be equivalent to that of a space cabin occupant. Consequently these recommendations are considered to be unjustified.

Jones and Prince [60] (1964) also undertook a study in which they considered the effects of confinement along with numerous other aspects of habitability. They evaluated performance and physiological function in terms of crew volume, and mission duration, assigning the ratings of satisfactory, mildly degraded, and degraded, as indicated, to each of the measures. Figure 9, from their work, illustrates some of their findings. It will be noted that for operational vehicles, as the mission duration increases from three hours to 83 days, the permissible volume per man increased from 25 cubic feet to 1800 cubic feet. At the same time, beyond 5 days and 90 cubic feet both the performance and physiological ratings show degradation regardless of increase in volume. For simulated missions, any volume above 100 cubic feet per man resulted in satisfactory performance and function.

The general conclusions of Jones and Prince were that:

(a) Volumes per man below about 40 cubic feet can produce severe degradation in physiological functioning and performance.

(b) Volumes per man between 45 and 90 cubic feet in simulated vehicles are on the borderline of missions up to 5 days and may cause substantial difficulty for missions of longer duration.

(c) Volumes per man between 100 and 200 cubic feet appear to be satisfactory for missions up to 30 days, although there is no operational test of this proposition.

(d) Factors other than volume, probably associated with isolation, will be the prime determinants of habitability for missions beyond 30 days.

With the exception of the duration noted in the last statement, and the volume noted in the first, these conclusions are in general agreement with those of this study.

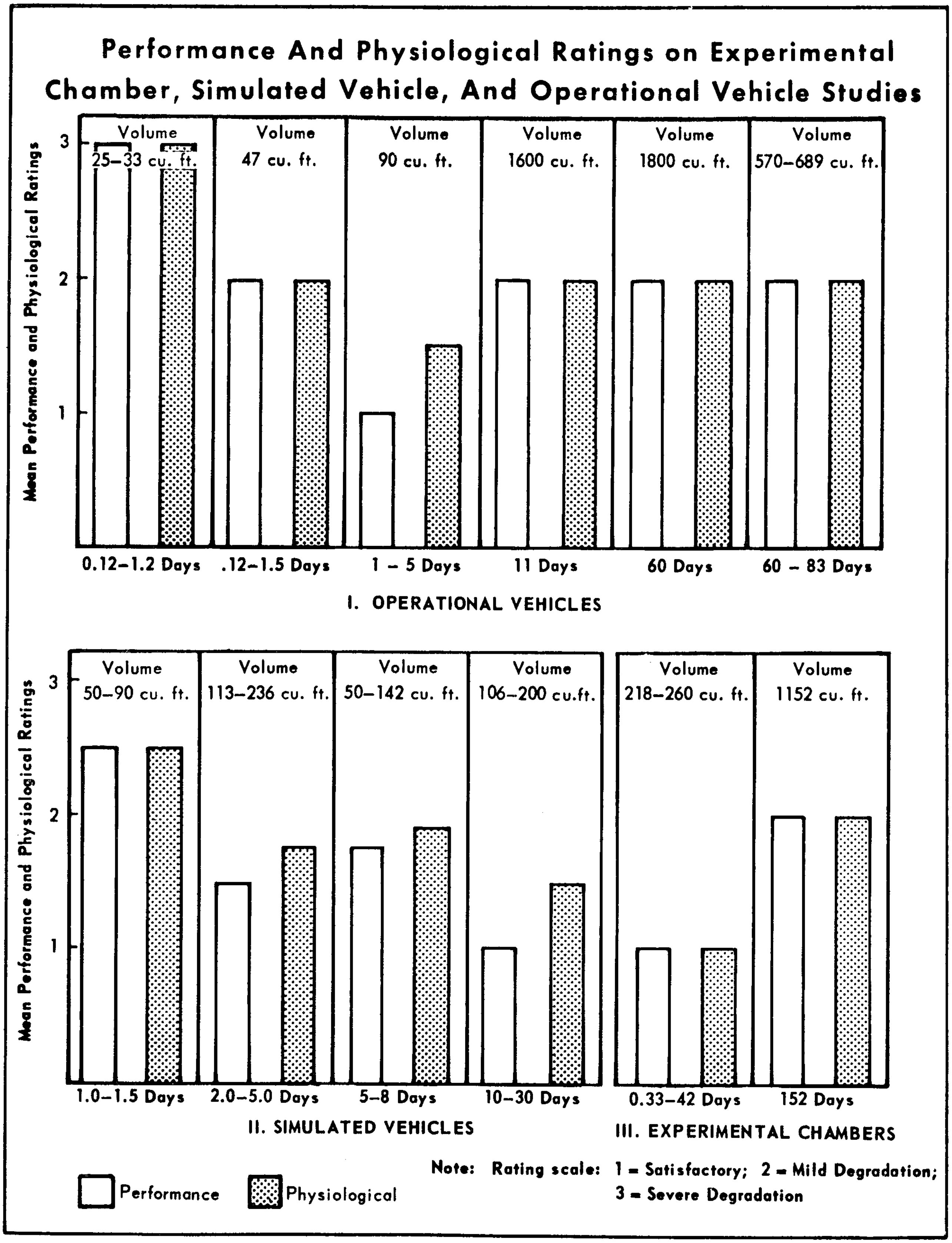


Figure 9. Performance and Physiological Ratings on Experimental Chamber Simulated Vehicle, and Operational Studies

Source: Jones and Prince (ref. 60)

The studies discussed above are analytic in nature, in the sense that the authors have analyzed available experience and from the information so obtained have attempted to define thresholds. Another approach has been made by Davenport et al.[20] (1963) in which the authors define the minimum free volume required for different individual crew activities and show that the total activities for various mission durations and crew sizes demand a certain total minimum free volume. A significant feature of their approach is the realization that while the volume required for some activities would vary very little with duration, other activities would likely be volume sensitive to mission duration.

The initial step of the authors was a definition of crew activities as indicated in Table 9. Using anthropometric data for a 90^{th} percentile astronaut, minimum functional volumes were then calculated for the seated work station, the standing work station (e.g., for maintenance), exercise area, sleep area, toilet, galley area, rest area, and other functional areas. Estimates were also made regarding the number of such areas required per number of crew.

These volumes were then examined in the light of their variation with mission duration and with crew size, and the volumes adjusted accordingly, bearing in mind such considerations as time-sharing, and the requirement for increasing crew size with longer missions. It might well be argued, and with justification, that while the initial volumes based on anthropometric data are no doubt valid, the adjusted volumes are somewhat arbitrary, and of course are not directly based on experimental data. In particular, it is debatable if more free volume per man is required for a large crew as compared to a small crew, in view of the greater potential for time-sharing and multiple use of facilities and equipment.

The results of their calculations for missions of one day to 400 days with crew sizes of one, three, five, and ten men are illustrated in Table 10 and Figure 10. It will be noted from the data that the available volume per man for a 30 to 60 day mission is in accord with that recommended by this study.

Table 9. Basic crew activities in manned space missions.

<u>Command and Control Operations</u> (attitude control, orbit, maintenance, launch and recovery, rendezvous, communications, navigation, logistics, data recording, artificial "g" control, etc..)
<u>Systems Control/Station Keeping</u> (environmental control, energy management, sybsystem monitoring, waste control, etc..)
<u>Research or Special Mission Operations</u> (planning, equipment operation, laboratory procedures, data recording and handling, onboard analysis, etc..)
<u>Maintenance</u> (inspection, servicing, fault detection and isolation, removal and replacement, repair, adjustment, preventive measures, periodic checkout, etc..)
<u>Crew Personal Operations</u> (food preparation and consumption, defecation and urination, bathing, grooming, clothing, change, exercise, recreation, biomonitoring, medical care, rest, etc..)
<u>Crew Skill Maintenance</u> (emergency procedures drill, complex task practice, specialty training, etc..)
<u>Crew Locomotion</u> (ingress and egress from functional areas.)
<u>Sleep and Privacy</u>

Source: Davenport et al. (ref. 20)

Table 10. Approximate minimum volume requirements (ft^3) related to basic crew activities in space vehicles.

BASIC ACTIVITIES	DESIGN MISSION DURATION (DAYS)														
	1	3	5	10	15	20	30	45	60	75	100	125	150	200	250
<u>1-Man Crew</u>															
Command & control Operations	25	25	25	25	25	25									
and															
Systems Control/ Station Keeping	25	25	25	25	25	25									
Maintenance			5	15	15	20									
Crew Personal Operations		10	10	10	15	20									
Total	50	60	70	75	80	90									
<u>3-Man Crew</u>															
Command & Control Operations			50	50	50	50	50	50	50						
Systems Control/ Station Keeping			50	50	50	50	50	50	50						
Maintenance			5	10	15	20	30	35	40						
Research/Special Mission Operations			35	45	45	50	60	60	65						
Crew Personal Operations			50	55	50	55	70	75	75						
Locomotion & Access			30	30	40	40	50	50	60						
Sleep/Privacy				25	25	25	25	25	25						
Average per man			75	87	95	100	112	115	122						

Source: Davenport et al. (ref. 20)

Table 10. (Continued)

BASIC ACTIVITIES	10	15	20	30	45	60	75	100	125	150	200	250	300	350	400
5-Man Crew															
Command & Control Operations	100	100	100	100	100	100	100	100	100	100	100	100	100		
Systems Control/ Station Keeping	50	50	50	50	50	50	50	50	50	50	50	50	50		
Maintenance	10	20	30	40	50	50	60	60	70	70	80	90	100		
Research/Special Mission Operations	90	100	110	120	130	140	150	155	160	160	170	175	180		
Crew Personal Operations	150	150	160	170	175	180	185	190	195	200	220	240	260		
Crew Skill Maint.			10	10	15	20	20	20	20	30	30	30	35		
Locomotion/Access	50	50	60	60	70	70	70	80	80	90	90	100	110		
Sleep/Privacy	50	50	50	60	60	70	70	80	80	90	90	100	100		
Average per man	100	104	114	122	130	136	141	147	152	159	166	177	187		
10-Man Crew															
Command & Control Operations			100	100	100	100	100	100	100	100	100	100	100	100	100
Systems Control/ Station Keeping			100	100	100	100	100	100	100	100	100	100	100	100	100
Maintenance			100	125	150	160	175	190	210	220	230	250	275	290	300
Research/Special Mission Operations			175	180	185	190	195	200	210	215	220	225	230	235	240
Crew Personal Oper.			425	475	525	550	570	585	600	620	640	650	670	690	700
Crew Skill Maint.			20	20	30	40	45	50	55	60	60	60	70	70	80
Locomotion/Access			150	150	160	160	165	165	175	175	180	180	190	200	220
Sleep/Privacy			300	300	325	400	425	450	500	525	550	575	600	625	650
Average per man			137	145	158	170	180	184	195	202	208	214	224	231	239

One major consideration bears further examination. This study of Davenport et al.[20] is based on the concept of functional free volume, namely, that volume on the basis of anthropometric data which is required to perform a given task or set of tasks. As has been shown, however, in earlier discussion, confinement within a limited volume for a given length of time produces psychological and physiological disturbance in man even if that volume is apparently adequate for all, or most, purposes. Thus the extrapolations of these tables can be considered valid as design criteria only when they do not conflict with constraints imposed by psychophysiological limitations. In consequence, it is doubtful if the recommendations proposed by Davenport et al.[20] for missions beyond about 60 days can be accepted as valid criteria without experimental confirmation. They do, however, provide useful guidelines in determining the minimum volume required for satisfactory completion of given tasks in a space vehicle.

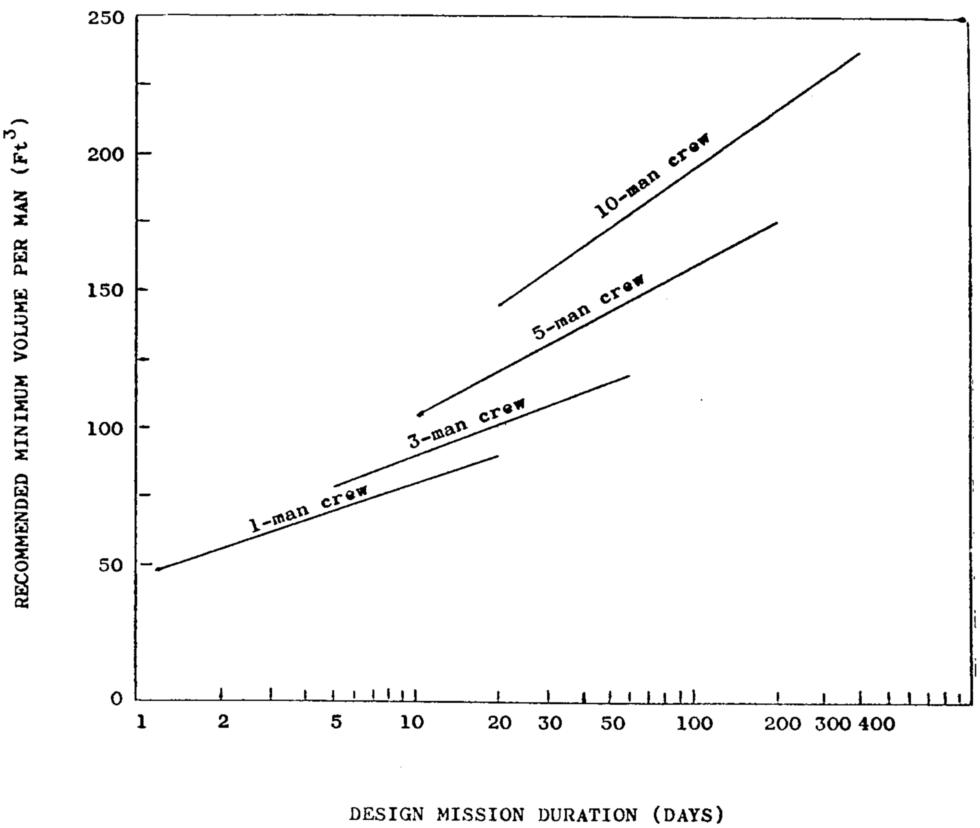


Figure 10. Preliminary requirements for crew volume versus space mission duration.

Source: Davenport et al. (ref. 20)

DISCUSSION AND CONCLUSIONS

From consideration of the foregoing it is clear that confinement, when defined as a physical and temporal limitation on the activities and translational motions of an individual or a group, is a stress-inducing entity which can be discriminated from, although it is sometimes accompanied by, perceptual and social isolation.

At the same time, a body of knowledge on the effect of confinement per se is generally lacking, and information about the human response in most circumstances can only be obtained by extracting it from the results of studies carried out for other purposes or contaminated by other gross variables in the environment. On the whole, the most pertinent information is garnered from studies of simulated space missions. Even these, however, can be suspect, since they frequently include exposure to artificial atmospheres and manipulation of work-rest schedules. For the acquisition of basic data there is a need for further studies of confinement per se, where perceptual isolation is minimized; while for design purposes, with respect to available hardware, layout and procedures, there is a need for further simulated missions embodying in the simulator a close approximation to actual mission conditions.

Psychological Response

While perceptual aberrations are not associated with confinement per se, the single isolate in close confinement is frequently also in a state of varying perceptual isolation, and responds with the occurrence of various types of perceptual aberrations. With motivation and experience, however, these can be accepted and do not necessarily lead to decrements in performance. With two subjects, the incidence of perceptual aberration is markedly reduced, and with more than two its occurrence has not been recorded. There is a need for further analysis of the elements within the individual and the environment that contribute towards the occurrence of perceptual aberration, and for reduction of the latter by selection of the individual, and manipulation of the environment.

Emotional reactions, expressed as hostility and resentment, are not uncommon in confinees. In the case of the solitary isolate these tend to be directed against the impersonal environment or against outside investigators, if there are such. With a multiple crew, the resentment is more commonly directed against colleagues, although if motivation and discipline are high these reactions will frequently be latent rather than overt. Interpersonal relationships among a carefully selected well motivated crew do not seem to give rise to problems, at least up to 30 days confinement. Research, however, is needed in the development of techniques for the prediction of group relations and group response, and for the selection of individuals with different personality traits who will unite to form a cohesive, productive group. The current astronaut selection program, which is oriented towards selecting self-reliant leaders, would not appear to provide for this group interaction.

Where the restrictive element of confinement is severe, discomfort is marked. This problem should be alleviated to some extent by weightlessness.

Intellectual or complex psychomotor performance, even under conditions approaching the intolerable, is relatively little affected by confinement per se although it is reduced under conditions of perceptual isolation. Where confinement is severe enough to produce physiological incapacitation, and is aggravated by other harassing environmental conditions, a significant decrement can be measured, as in the Hicks APC studies, but otherwise the minor decrements observed are probably due to fatigue arising from demanding work schedules, or from boredom associated with performance of repetitive and apparently useless tasks. For prolonged missions it will be necessary to ensure that available time is fully occupied with subsidiary scientific and biomedical tasks. The occurrence of procedural error in simulated operational tasks points up the necessity for continued training during an actual mission.

The significance of disturbances in time estimation has probably been exaggerated in the literature. It is true that where consensual validation is poor, as in conditions of perceptual isolation, time estimation may be grossly disturbed. However, where subjects are engaged in time-dependent tasks, as will be the case in space missions, and where consensual validation is as complete as the circumstances allow, then time-estimation is not apparently affected. It would be useful, however, to confirm this hypothesis by actual controlled experiment.

Measures of such qualities as simple and choice reaction time, vigilance skill, monitoring and tracking ability, have been somewhat haphazardly approached in some cases, with little in the way of a clear-cut attempt to isolate the parameter being measured. In general, no change was observed attributable to confinement and probably none should be expected. The effect of the confinement on these measures is probably of less significance than the nature of the other environmental conditions under which the testing is undertaken. For the record, however, it would be valuable to obtain data on these responses under a rigid protocol.

Many questions remain unanswered. It is clear that in a motivated subject a high level of performance can be maintained up until the point of intolerability. But it is not clear, what constitutes intolerability, what arouses the resentment and hostility, and what contributes towards the fear or even panic that arises in some subjects, even in the absence of hallucinations or perceptual distortions. In seeking the answers, however, the importance is again emphasized of distinguishing between confinement and perceptual isolation. The latter is not a major feature of operational space missions, even single man missions, and consequently the perceptual distortions associated with it are not a problem. In addition, the day of the single-man mission is passing. A major psychological problem of the future, and in fact even of the present, lies in developing predictive measures of group response, group interaction, and of devising techniques by which an individual can be evaluated with respect to his ability to participate productively in a group.

The pattern of change with time requires further study. The Russian work on prolonged confinement remains unconfirmed here. A trend towards

As has been noted there are indications that beyond 7 to 10 days the response is more affected by duration than restriction, but whether this situation is maintained beyond 60 days is not known.

The physiological effects specifically attributable to reduced mobility are manifested most dramatically in the phenomenon of cardiovascular deconditioning, which becomes evident following a few days of close restriction. While the effects of deconditioning are probably of little moment within the orbiting or interplanetary vehicle, they assume considerable significance during re-entry and extravehicular activity. With the additional tendency towards deconditioning occasioned by weightlessness it is obvious that a significant hazard will exist. Much work remains to elucidate the mechanisms responsible for the deconditioning process and to devise suitable and practicable methods to prevent it. The specific usefulness of drugs, isotonic and isometric exercise, pulsatile and non-pulsatile positive or negative pressure, centrifugation, active and passive trampoline "slosh," and fluid loading, have still not been definitively evaluated.

Along with the deconditioning there is some indication of loss of muscle mass, and strength, and breakdown of protein, as suggested by disturbed nitrogen balance.

The results of investigations of fluid and blood volume, and body weight, are not well defined since they reflect dietary availability and habits, work requirements and mobility, as well as confinement. There would appear to be a trend, however, particularly where confinement is severe, towards a reduction in total body water, total blood volume and plasma volume, along with a decrease in body weight. How much of the fluid loss is associated with posture within the confined chamber, how much is associated with ambient conditions of heat, humidity, and altitude, and how much reflects altered fluid distribution within the body has not been determined; while how much of the weight reduction represents fluid loss, how much muscle atrophy, and how much dietary is not clear. Definitive studies are needed, the more so since most of the current information has been gathered retrospectively from work undertaken for other purposes. Since these findings are also observed in subjects exposed to simulated weightlessness, and to some extent during progressive disinterest with time could have a profound influence on the success of a long duration mission, and if, as would appear likely, it in fact occurs, methods must be developed to counteract it.

Physiological Response

The pattern to be described is not fully confirmed, and requires considerable validation before it can be stated categorically. However, it appears that the physiological response is one of non-specific reaction to stress, combined with specific changes attributable to the reduced mobility. The non-specific changes are manifested by a typical pattern of excretion of catecholamines and corticosteroids, by alteration in galvanic skin resistance or conductance, by variations in pulse rate, respiratory rate and blood pressure associated with the emotional status of the individual, and by changes in the EEG. With progression of the confinement, the initial heightened activity begins to show the effects of an adaptive process during the second week and appears to be maintained for about two months before a resurgence of stress phenomena occurs. Since the resistive stage in stress theory is commonly associated with reduced resistance to new forms of stress, it is possible that during this time a crew member might succumb more readily to some fresh assault such as toxic contamination of his environment, infection, or some other potentially hazardous change in his environment. This deserves investigation.

Following the resurgence of stress reactions there develops a progressive emotional indifference and physiological deactivation which continues for some time after confinement has ceased.

It is emphasized that the pattern described above is largely unconfirmed except for the early stages. Most of the work in this country under conditions of close confinement has involved studies of 7 to 14 days. The few studies of 30 days or more have been carried out in conditions of moderate confinement with free mobility, and apart from submarine studies there has been practically no work involving confinement of longer than 30 days duration. There is a great need for studies of up to six months or more in length, both to confirm the suggested pattern and to determine how much the response is a function of duration and how much a function of restriction.

orbital flight, the respective contributions of weightlessness and confinement to their occurrence must be distinguished.

Another finding of similar import is also significant, namely, the excessive excretion of calcium. Although observed only in one subject, the fact of its occurrence deserves attention, since the phenomenon is also found under weightless conditions. It is perhaps noteworthy, however, that it was observed under conditions of fairly severe confinement in a subject of sedentary habits participating in somewhat unwonted exercise. Where confinement was much less severe, with free mobility, no excessive calcium excretion was observed.

Pulmonary function studies deserve more attention. Those that have been carried out generally reflect the effect of very artificial atmospheres and pressures other than sea-level. Changes in function due to prolonged confinement per se seem probable but have yet to be demonstrated.

Other physiological and biochemical findings are unremarkable.

Tolerance of Confinement and Volume Requirements

Tolerance of confinement can be expressed as a function of duration and available volume. It is influenced, however, by other factors including the number of persons simultaneously confined, the motivation and experience of the subjects or crew, the quality of leadership and group compatibility, physical fitness of the crew and the use of exercise regimes, suitability and habitability of the immediate environment, suitability of work and rest scheduling, meaningfulness of the activities and tasks in which the subjects or crew are engaged, existence of recreational activities, and informed knowledge of the status and duration of the mission.

All of these factors require further investigation, and comments have already been made on some. Particular attention, however, is directed to the use of exercise programs. From the limited data, it would seem that established and continued exercise programs might well have a beneficial effect not only on the physical condition of a subject but on his psychological state and performance capacities as well. The meaningfulness of tasks is another field worthy of attention. The push-button automatism by which designers attempt to reduce the load on the orbiting astronaut may be of mixed value in prolonged missions. Considerable care must be exerted during the integration of the astronaut into the machine-system to ensure that he does not become merely a robotic portion of a servo-loop with other capacities which are utilized only in emergencies. There is already a body of literature indicating the extent of man's capacities, but little if anything has been done to indicate how much these capacities must be used, how meaningful must be the tasks, and how much feedback they should provide to promote optimum performance, singly and in groups.

With respect to actual tolerance levels, it was shown in the body of the text that up to about 7 to 10 days the acceptable volume of free space increases from about 25 to 125 cubic feet per man. From 7 to 30 days there is a slight increase in acceptable volume to 150 cubic feet, but thereafter considerations other than volume appear to be limiting. Beyond 30 days, hard numbers cannot be given, but it seems reasonable to assume that about 150 cubic feet per man might be acceptable up to 60 days. Extrapolation thereafter is futile at this time, and there is much need for confinement experimentation beyond 30 days. In spacecraft, the possible ameliorating influence of weightlessness must be borne in mind.

Below these limits there is a circumscribed region where lesser free volumes are acceptable with a calculated risk of moderate impairment. Less than 25 cubic feet is totally unacceptable beyond a couple of days, and even then would probably give rise to significant impairment. Thereafter, the threshold of unacceptability rises to meet the threshold of acceptability at a duration of about 60 days and a volume of about 150 cubic feet per man.

The threshold of unacceptability, then, represents a minimum volume at which current or future performance level is barely adequate, and/or physiological changes are just acceptable. The zone of detectable impairment reflects the influence of the limited duration, volume, and also factors other than volume. Where the two threshold approach one another, the effects of limited volume per se no longer increase with duration, at least to about 60 days, and factors other than volume become constrictive.

Thus, above the threshold of acceptability, volume is not a major constraint regardless of duration. Below the threshold of unacceptability volume is the major constraint regardless of duration. Between the threshold the effects of volume may be modified by other factors; and between about 15 and 60 days the minimum required volume remains constant and adverse effects are related to the influence of other factors.

It is obvious that one of the great needs is for data on confinement within free volumes of about 150 cubic feet per man under simulated mission conditions for durations greater than 30 days. It seems probable that 60 to 120 days is a somewhat critical region from the point of view of both psychophysiology and spacecraft design. Beyond that duration of mission it would appear that the design of spacecraft and availability of boosters will be such that from the engineering viewpoint volume will not be a major limiting constraint.

Confinement, then, is a stress-inducing state, the extent of the resulting stress depending on the severity and duration of confinement, habitability of the confined space, work, rest, recreation and exercise schedules, and personal factors within the subject. Within a spacecraft, some of the effects of confinement will be mitigated and some aggravated by weightlessness. With careful individual and group selection, however, a crew can maintain acceptable performance and physiological homeostasis for predictable durations up to at least 60 days within a confined space provided the free volume is above a definable threshold, and habitability, work, rest, recreation, and exercise schedules are optimum.

ANNOTATED BIBLIOGRAPHY

1. Adams, O. S., Aircrew fatigue problems during extended endurance flight. Phase I. Planning. WADC-TR-57-510, 1958.

   This paper outlines a plan for an experimental program designed to determine the effects of confinement induced stresses on a five man crew isolated in a flight station for a period of 120 hours. Experimental crew compartment is described and illustrated, and the performance tasks, programming and recording instrumentation, together with the laboratory techniques planned for use in the experiment, are explained.

   The crew compartment has floor dimensions 280 inches long by 76 inches wide, or a total floor area of approximately 115 sq. ft. Sidewalls rise vertically from the floor to 40 inches at front of the compartment and 60 inches at rear. Ceiling forms a concave surface with a 51 inch radius of curvature. Total compartment volume is approximately 550 cubic feet. Compartment is divided into nine functional classes, namely, work area, leisure area, food preparation and storage area, toilet area, lighting, airconditioning and ventilation, facilities for direct observation, acoustical insulation, and communication facilities. Work space has a floor area of 59.5 sq. ft. Leisure area (approximately 44 square feet of floor space) is designed to include minimum facilities necessary for satisfying personal needs during 120 hour confinement. It includes two bunks, 76 x 24 inches, for resting and sleeping. Lower bunk is located 16 inches above the floor and the upper bunk 46.5 inches above the floor. Eating unit is a rectangular area 21 inches by 54 inches. Food bar, for food preparation and storage is 32 inches wide. Dimensions of toilet are 22 x 40 inches.

   This facility (Lockheed, Georgia) has been used for several confinement studies described elsewhere.

2. Adams, O. S., Chiles, W. D., Human performance as a function of the work-rest cycle. WADD-TR-60-248, 1960.

   As title implies this study is primarily concerned with work-rest schedules, but has elements of confinement in that 16 subjects were confined within an area of approximately 3600 square feet. Area included sleeping quarters, work quarters and a leisure area. 16 subjects

2. were divided into two groups of 8, each of which was subdivided into groups of four. Work-rest schedules of 2 and 2, 4 and 4, 6 and 6, 8 and 8, were investigated. Performance included arithmetic computation, pattern discrimination, warning light monitoring, probability monitoring, auditory vigilance, and observational and attitudinal measures. Confinement was not complete in that subjects were allowed to leave the area for meals. There are virtually no comments on the confinement aspects of the study but the degree of stress imposed upon the subjects was comparatively mild. The duration of confinement was 96 hours, and in a questionnaire 10 of the 16 subjects indicated they believed they could have continued to perform satisfactorily for more than 4 days. There were indications that 2 and 4 hour cycles resulted in more favorable subject adjustment than did the 6 and 8 hour cycles.

3. Adams, O. S., Chiles, W. D, Human performance as a function of the work-rest ratio during prolonged confinement. WADD-ASD-TR-61-720, 1961.

Subject sample consisted of two B-52 combat crews, the first (non-volunteer) composed of five men, and the second (volunteer) composed of six men. Subjects were tested in advanced system crew compartment mock-up divided into three sections, a five station work area, a leisure area, and a sleeping area. Total volume approximately 1100 cubic feet. Height not given but appears to be about 8 feet. On duty, subjects occupied assigned position in work area. Off duty, they were restricted to leisure area or to adjacent six bunk sleeping area. Both areas were adequately illuminated. Sleeping area was maintained in semi-darkened condition. Speakers provided continuous quiet noise of approximately 85 db to mask outside sounds. Crews were tested separately on around-the-clock schedule of four hours duty and two hours rest for period of 15 days. A battery of five performance tasks designed to test psychological functions such as mental computation, pattern discrimination, monitoring and vigilance was used throughout the tests. Four physiological measures, skin resistance, skin temperature, heart rate, and respiration rate, were used. Meals were furnished and placed in the food compartment in the leisure area at specified times. Two members of the crew ate at one time. Toilet facilities were available during leisure and during a thirty minute low performance period of task program. Intercom conversation

3. (Cont) was kept to a minimum, e.g., apparent malfunction in equipment or emergency. Results showed a significant between-day effect for four of tasks. Arithmetic computation, monitoring, and auditory vigilance reflected a trend toward decrement, while pattern discrimination was associated with improvement. A significant within-day effect (diurnal variation) was observed in all performance tasks. A significant between-day effect was obtained for three physiological variables, (skin resistance, heart rate, and respiration rate). Daily trend was decrease in the level of autonomic activation (i.e., an increase in skin resistance, and decrease in heart rate and respiration rate). All four measures showed a prominent within-day effect. Although wide between group and between subjects variations occurred in both performance and physiological measures, it was concluded that with a minimum amount of selection, highly motivated crews can maintain acceptable performance levels on a four on and two off schedule for a period of two weeks and perhaps longer. Two subjects maintained a high performance level throughout duration of study. Seven of eleven subjects showed significant improvement with time in performance of learning task (pattern discrimination). The majority of subjects indicated they could have continued the test for at least another 15 days if necessary and important.

4. Alluisi, E. A., Chiles, W. D., Hall, T. J., Combined effects of sleep loss and demanding work-rest schedules on crew performance. WADD-AMRL-TDR-64-63, 1964.

This study is a continuation of other confinement studies performed by the same group. It begins with a summary of the previous studies which indicated that with a relative minimum of selection, highly motivated subjects can maintain a schedule of 4 hours on and 2 hours off for at least 2 weeks duration and perhaps for a month, although performance is universally better with a 4 hour on and 4 hour off schedule. The current studies (HOPE-IV to HOPE-VI) were conducted to examine the combined effects of sleep loss and work-rest scheduling (4-2 or 4-4) on performance tasks. Two of the tests employed 10 subjects working a 4-4 schedule for 12 days. During days 6 and 7, the subjects worked continuously for 44 hours alternating 4 hour duty at work stations with 4 hour periods of extra duty in leisure area. In the other two tests, 6 subjects were employed, working a 4-2 schedule for 12 days.

4. (Cont) During the 6th and 7th days, subjects worked continuously for 40 hours, alternating normal work station duty with extra duty in leisure area. Results showed that sleep loss will result in performance decrements. Performance of operators on 4-2 schedule is depressed to a greater degree than those on the 4-4 schedule. Impact of sleep loss on specific tasks depends on position of tasks in the activity-passivity continuum and amount of and nature of time sharing. Performance returns to approximately the normal expected level after subjects on 4-4 schedule have 2 sleep periods and those on 4-2 schedule have had 3 sleep schedules. Subjective reactions of individuals as to how they have been performing are related only in a gross manner to objective measures.

5. Alluisi, E. A., Chiles, W. D., Hall, T. J., Hawkes, T. R., Human group performance during confinement. WADD-AMRL-TDR-63-87, 1963

This study describes two experimental investigations. The first, "HOPE-II," concerns a six man crew working for 15 days on a 4-2 schedule, while in the second, "HOPE-III," two 5-men crews were tested over a 30 day confinement period, on a 4-4 schedule in alternate shifts throughout the 30 days. To avoid the typical end effects, appearing as a spurt in performance during the last 2 or 3 days, subjects in the latter study were lead to expect a 40 day confinement. Subjects for HOPE-II were 6 Air Force Academy Cadets, all volunteers. Criteria used in selection were those for Project Mercury astronauts. Subjects of HOPE-III were broken into two 5-men crews. Subjects were tested in an advanced system crew compartment mock-up consisting of three sections, a five station work area, a leisure area, and a sleeping area, to a total volume of approximately 1100 cubic feet, half of which is devoted to work station and leisure area, and half to sleeping. On duty, each subject occupied assigned positions in the work area. Off duty, subjects were restricted to leisure area and sleeping area. Work and leisure areas were adequately illuminated; sleeping area was maintained in semi-darkness. Broad-band noise was continuously present at constant level of about 85 db. Subjects were given performance tasks, four of which were individual tasks, and two tasks requiring group participation. Pulse rate and axillary temperature were measured regularly

5(Cont) by the subjects. Subjects kept daily logs. All activities were rigidly timed and regular shift changes were accomplished. Adequate regular meals were provided and toilet facilities were available. The operation was in the form of a closed system with the use of an external intercom for operational purposes only. Problems of sleep and alertness related to the scheduling were observed. All subjects made note of minor physical discomforts associated with the confinement period. Morale started high but tended to drop during the first few days and then remained relatively constant except for noticeable rises at several specific points, e.g., at mid-points of confinement periods, or minor celebrations. Subjective irritability, sleepiness, and fatigue were observed. None of these adversely effected task performance. No hallucinations or illusions were observed. Results of performance measures were not clear cut. Variations appeared to be related to motivation, diurnal cycling, and duration of the task. The greatest differences were probably a direct reflection of the relative impacts of the two work-rest schedules. At least some highly motivated subjects can follow a 4-2 schedule without showing decrements. The extra hour of performance per day, however, is achieved at a price, namely, the inability of the subjects to sustain performance at the level generally maintained by a comparable group working only 12 hours per day on a 4-4 schedule.

6. Bexton, W. H., Heron, W., Scott, T. H., Effects of decreased variation in the sensory environment. Canad. J. Psychol. 8:70, 1954.

Twenty-two male college subjects were paid to lie on a comfortable bed in a lighted cubicle 24 hours a day except for hygienic purposes. Subjects tended to spend the earlier part of the experiment in sleep. Later they slept less, became bored, and appeared eager for stimulation. Unusual emotional lability developed during the test. Subjects were unable to concentrate for long. Performance on psychological tests was impaired. Complex visual hallucinations occurred with a vividness that interfered with sleep. Some auditory, kinesthetic, and somesthetic disturbances were reported, along with feelings of "otherness" and bodily "strangeness".

7. Birkhead, N. D., Issekutz, B., Bligzard, J. J., Cardiodynamic and metabolic effects of prolonged bed rest. AMRL-TDR-63-37, 1963. (Author's Summary)

To evaluate the circulatory and metabolic effects of prolonged inactivity, urinary nitrogen, calcium, and phosphorus excretion were measured in four healthy trained men on a constant diet (2500 Cal., 77 gm protein, 74 gm fat, 385 gm CHO, 1724 mg calcium) during 42 days of continuous supine bed rest. Maximum oxygen uptake and hemodynamic response to 70° head-up tilt and supine bicycle exercise at 3 and 6 times resting O_2 uptake levels were determined pre- and post-bed rest. Urinary excretion of calcium and phosphorus increased within the first six days. Calcium excretion reached a peak approximately twice control values after 24 days. No significant change occurred in urinary nitrogen. Tolerance to 70° head-up tilt and physical work capacity decreased following bed rest, but a satisfactory cardiodynamic response to supine exercise was maintained. Physical work capacity returned to near pre-bed rest values after 18 days of retraining.

8. Bruce, J. C., Escape from Alcatraz., McGraw Hill Book Co., Inc., New York, 1963.

9. Burns, N., Environmental requirements of sealed cabins for space and orbital flight., A second study, Part I. NAMC-ACEL-413, 1959.

This is the first of 6 reports describing the second Naval confinement study. The confinement area previously described consisted of two compartments, the first for eating, recreation, and hygiene, and the second for work and sleeping. Continuous monitoring was undertaken. Six Naval enlisted personnel were selected on the basis of psychological and medical testing from a group of 24 volunteers from an original group of 40. These 6 men functioned as three 2-man teams. Measures of psychological behaviors during the 8 day period of confinement included tests of rigidity, or perseverance, of behavior, time estimation, suggestibility, analysis of group behavior, vigilance, and tracking. Results of the studies are presented in another paper. (Burns and Gifford, 1961).

10. Burns, N. M., Gifford, E. C., Environmental requirements of sealed cabins for space and orbital flights. A second study, Part II. NAMC-ACEL-414, 1961.

This paper reports the results of the performance tasks described in Part I of these same studies. Because of the small number of subjects used, the results were not very general and the authors insist that the findings are only suggestive. Performance on the tasks in which the operator function was routine and without apparent consequence deteriorated rapidly. Tasks where the operator could achieve some satisfaction and knowledge of results elicited a high quality of performance over a long period of time. In each of the time intervals studied, subjects in the confinement chamber overestimated the passage of time in comparison with control. Degree of overestimation increased as length of confinement increased. Authors discuss in detail the effect of consensual validation on the tasks involving reasoning ability and some degree of concentrated thought. They note that loss of information about external events, loss of cues about diurnal variation and temperature changes, lack of knowledge of activities of others, inadequate information with regard to performance of various tasks or to perception of certain stimuli all increase the feeling of detachment and add to the insecurity. Any way in which confinement or isolation is interrupted could be interpreted to provide an opportunity for consensual validation. Many of the early studies on sensory deprivation did not take this into account.

11. Catlin, R., The physiological effects of abnormal environment. Presented at Seminar in Aviation Health and Safety, Harvard School of Public Health, Boston, Mass. 1958.

This is a summary of the neurophysiological mechanisms underlying the symptoms of sensory deprivation and the effects of "brainwashing". Author points out that maintenance of complex cerebral functions is dependent on an adequate intensity and variety of environmental sensory impulses which are received by a peripheral sensory system, and, as exceptions, are passedonto a storing, comparing, utilizing system. Interference with the function of any of these three systems will result in a disorder of the more complex cerebral function. In addition to adequate environmental perceptions it is also necessary to develop an identity, by organizing, patterning, and comparing perceptions, and having an opportunity to compare the resulting ideations with the concepts of others and to test them in reality.

12. Celentano, J. T., Adams, B. B., Habitability and maintenance of human performance in long duration space missions. AAS-60-83, 1960.

This paper describes the nature of habitable environments and their significance in the maintenance of effective human performance. Among the important factors are: living space, food, water, atmospheric control, illumination, recreation, and personal services. Although man may function under adverse conditions, his performance effectiveness may be impaired and the frequency and duration of such performance should be held to a minimum consistent with system operating requirements. Normal operating situations should provide the best living conditions compatible with mission requirements. Factors of fatigue and morale play an important role in determining final level of performance. War time studies of operational fatigue have noted that adverse environmental conditions increase fatigue and lead to decrement in performance.

Habitability: Habitability includes the characteristics which determine environment and the facilities provided for sustenance and comfort. In addition to the necessities of life, factors are: compartment design, traffic control, air conditioning, lighting, sanitation, and recreational facilities.

Compartment Design: Provision of habitable compartments for work, sleeping, leisure time activities, and personal needs should be considered a means to an end. Cramped living quarters with little privacy can cause fatigue and poor morale. Inadequate quarters and physical discomforts have been cited as factors leading to fatigue and breakdown in combat pilots. Inadequate housing is considered one of the major causes of breakdown in concentration camps. Navy studies show that adequate space and privacy are important factors in maintenance of morale. For sleeping, study, and leisure, Navy recommends 90 square feet per man, including 40 square feet of unencumbered area. IGY polar expedition allowed nearly 100 square feet per man in sleeping area alone. Army Surgeon General recommends 72 square feet per man in troop barracks. Adequate area for living space appears to be about 90 square feet per man, depending upon use and length of stay. Single rooms are most desirable, but double rooms are acceptable. Barracks type sleeping arrangements are not desirable for long term confinement and do not provide significant saving in space. All habitable spaces should be grouped into functionally related units.

12 (Cont) Living units should include sleeping areas, bathrooms, clothing storage. Food unit should include kitchen, dining, food storage, dishwashing, and garbage disposal. Service unit with laundry and other service facilities is desirable. Separate recreation unit should be planned when possible.

This paper also considered habitability aspects of food, water, atmospheric control, illumination and color, recreation and services.

13. Celentano, J. T., Amorelli, D., Freeman, G. G., Establishing a habitability index for space stations and planetary bases. Presented at AIAA and ASMA Manned Space Laboratory Conference, Los Angeles, 1963.

This paper considers numerous factors relating to habitability and details a method to produce a habitability index by the use of a relative weighting system. Authors note that habitability is determined by the provision of those facilities to which the occupant would reasonably be accustomed. Requirements will be based on space flight duration, nature of mission and task to be performed, numbers of men to be involved, and distances to be traversed. Needs will change as programs alter and enlarge. Several types of manned space systems are expected to be in operation, namely, small single or two-man cabins for up to several days duration orbital flight, multi-manned vehicles with approximately two week duration, space stations,and planetary bases. Long duration habitations will first be centered about space stations and lunar bases. As basic factors determining habitability authors consider environmental control, nutrition and personal hygiene, gravitational conditions, living space and crew work-rest cycles and fitness programs. They note that the total cost of a system increases with the efforts to reduce the stressful effects on its occupants, and that conversely the more stressful the vehicle the greater the cost in selection and training of occupants. The longer the flight, the more essential the provisions for habitation become. The lower the habitability index, the greater the probability that man cannot effectively endure extended missions. They examine in some detail the problems associated with atmosphere control, thermal control, nutrition, personal hygiene and other water needs, noise, vibration, radiation, illumination, gravitational condition, work-rest cycles and fitness requirements, and living space. With respect to the latter, they note that cramped living quarters with little privacy can cause fatigue and poor morale, with consequent lowering of performance efficiency.

13. (Cont). Many other factors can be permitted to approach normal conditions if volume is sufficient. Conditions approaching normal with sufficient volume include ability of body to move freely, sensory variety, e.g., changing sound, smells, taste, and visual experiences, privacy and social protocol, accommodative body functions. Authors quote a Navy study for minimum space requirements per man. The quarters used for sleeping, study, leisure, should provide minimum of 90 square feet per man, including 50 square feet of unencumbered area. IGY polar expedition allowed nearly 100 square feet per man in sleeping area alone. A table shows recommendations for IGY expedition, Royal Navy, U.S. Federal prisons, U.S. Maritime Service, U. S. Navy. They also quote results from three confinement studies in simulated space cabins at NAA, S&ISD, which showed that life in very small cabins reflected reduced levels of metabolism, and a cardiovascular response almost commensurate with bed rest. First cabin was a mock-up of a small conical shaped chamber with exterior volume of 450 cubic feet, living volume 200 cubic feet, living space 39 square feet. Three men were confined for seven days. A second cabin had external volume of 3500 cubic feet, interior volume 1500 cubic feet, living space of 150 square feet. Four subjects were confined for seven days. Third cabin had an external volume of approximately 3200 cubic feet, interior volume 1600 cubic feet, living space 400 square feet. Two men were confined for four days. Cabin A provided 13 square feet living space per man, cabin B 37 square feet, cabin C 200 square feet. Confinement was continuous, with simulated space mission schedules and work-rest regime. Requirements for eating, sleeping, personal hygiene, and investigative procedures were provided. Various relative activity levels were assessed on assumption that minimum metabolic requirements were about 2000 Kcal per man-day. Assuming that amount of activity determines energy requirements, energy needs in Cabin A were almost those of bed rest, namely, 2300 Kcal. In Cabin B where room size was available for movement, activity increased but was still low (2550 Kcal per man-day). Cabin C, with large amount of free space, allowed activity levels similar to those of average office worker (2800 Kcal per man-day). From their data, optimum living space per man is about 90 square feet. Confinement within cabin A produced changes similar to those of bed rest. Assuming 90 square feet per man, 700 cubic feet per man was recommended for actual space cabin conditions for long durations.

14. Celentano, J. T., Copping, D. G., Falbaum, H. F., Martin, B. G.
Biomedical aspects of a 7 day space cabin study.
Presented at IAS Meeting, Los Angeles, 1962.

Paper starts with a brief history of confinement study. Details purpose of NAA study to investigate the physiological and psychological responses to prolonged confinement, and to serve as a pilot study for future research. Investigators used a space cabin mock-up for a three man crew, constructed of wood paneling with external conical shape. A 3 x 6 ft. section of wall was left unpaneled for ventilation, covered with fine mesh screen. There was an unencumbered volume of 200 cubic feet. Interior was divided into central crew area and area for other cabin equipment. Two operational couches were separated by center aisle with work space at one end. A one-man sleeping area was located under couch, and food storage under the other. Control panels were instrumented for vigilance measures and tracking performance. Work space contained equipment and a small wash basin. Subjects could stand upright only in middle of aisle. Cabin was located in 20 x 30 foot airconditioned room with interior walls painted flat black. Closed circuit TV and hardwire intercom provided communication. Biomedically trained subjects, age 22 to 33, with evidence of motivation expressed as volunteering, were utilized. Air Force rations, supplying up to 3300 Kcal were used as food, eaten as desired, unheated. Rations provided high energy, low bulk, relatively low residue, diet. Water was available, consumed as desired. Personal hygiene provisions were minimal. Urine was collected via relief tubes, and feces were deposited in plastic bag, weighed and removed. Psychological and biomedical measurements were made. Psychological measurements included vigilance, tracking and star sighting, intellectual performance, observation and recording of individual and interpersonal relations. No evidence of significant psychomotor or intellectual degradation was found. Biomedical measurements were selected to evaluate well-being or stress. They included oral temperature, blood pressure, respiration, and pulse rate. WBC, smears, Hb concentration, sed-rate, urinalysis, and 17-OH ketosteroids.

Work-rest cycles based on two hour blocks were programmed so that two subjects were awake at all times. Six hours sleep was followed by 2 hours testing; $1\frac{1}{2}$ hours for biomedical measurements, eating, and personal hygiene. Relaxation not specifically scheduled. No exercise programmed.

Results: All subjects lost weight, partly due to tissue consumption and partly from water loss. Authors devote considerable time to calculations determining relative tissue loss and water loss.

14. (Cont). All subjects experienced mild starvation and dehydration. From their calculations authors claimed energy expenditure equivalent to 2300 Kcal/day for 70 Kg man. Much complaint about primitive personal hygiene provisions. Blood pressure (diastolic) and pulse rate showed downward trend except toward completion. Oral temperature tended to be sub-normal. No apparent shift of diurnal cycling. WBC and sedimentation rate showed no significant deviation. A relative decrease was found in polymorphs, and a relative increase in lymphocytes. Hemoglobin concentration was elevated in two subjects, perhaps from dehydration. High urine specific gravity and low urine output also suggested dehydration. Some acetone was also noted early in two subjects, perhaps from starvation. 17-OH ketosteroids were above normal in two subjects on several occasions, probably indicating stress. All subjects complained of fatigue and sleepiness. All subjects experienced rise in blood pressure and increase in heart rate on leaving cabin, complaining of dizziness and weakness, and fatigue after walking. Complaints did not subside for several days.

15. Chambers, R. M., Fried, R., Psychological aspects of space flight. in Physiology of Man in Space. Ed. J.H.U. Brown, Academic Press, New York and London, 1963.

Among other comments, authors note the effect of confinement on higher mental abilities. They list a number of different types of errors which appear during the performance of tasks in any prolonged confinement environment. They discuss personality and emotional behavior occurring in confinement and isolation. They note that isolation refers to the detachment or separation of a person from his normal, social, and physical environment; confinement refers to closing, restricting, and restraining of the person within a specific physical boundary, as in a capsule, container, or space suit. The combination results in sensory alteration which indicates a change in the quantity and variety of sensory stimulation which the individual receives. They discuss sensory alteration in detail but point out that caution must be taken in generalizing from sensory deprivation studies to space flight, since in space flight a wealth of stimuli may be provided. They note that long term confinement under suitable conditions can be tolerated by man, as demonstrated during the Nautilus cruise where ideal temperature, humidity, oxygen, and CO_2 requirement was maintained, along with fresh water, excellent food, reading and musical entertainment, games, tournaments, and incentive awards. Cruise lasted over 45 days.

16. Chiles, W. D., Experimental studies of prolonged wakefulness. WADD-TR-55-395, 1955.

Author describes a study in which each of four trained pilot subjects sat individually in an aircraft cockpit for 56 hours. No physical description of the cockpit is given nor is it stated whether the subject was allowed out of the cockpit at any time. During first 18 hours he was allowed to relax, although monitoring the occasional appearance of a light. During next 19 hours subject conducted a clock-type test in which he estimated the position of a pointer. During most of the last 18 hours subject was again permitted to relax except for monitoring, but for last half hour subject was again alert. Two subjects, on completion of 56 hours, flew 3 ILS passes on a Link trainer. Results showed a loss in the subjects'ability to remain alert, as measured by the monitoring test and clock test. At the same time, performance on the Link trainer remained adequate. The latter suggests the effect of motivation. The loss in alertness was not continuous nor consistent, but variable. Author makes no comment on the relationship between wakefulness and confinement.

17. Christensen, J. M., Psychological aspects of extended manned space flight. WADD-AMRL-TDR-63-81, 1963.

This paper discusses the psychological aspects of a projected manned Mars Mission. Author mentions problems of isolation and confinement but points out that while the crew will be physically confined, it will not be mentally confined nor will it be isolated. The crew will not suffer stimulus impoverishment. He notes that the crew will be highly motivated and will have had previous experience in difficult and even hazardous tasks. Elements of boredom will occur with thorough knowledge of the various tasks, and the challenge is to design a system that will require and use crew members in essential jobs, challenging enough to prevent monotony and boredom, yet sufficiently below maximum level of capability to allow for possible performance deterioration or for emergencies. Jobs, however, must not entail performance of sham tasks that are included simply to keep crew busy.

18. Clark, B., Graybiel, A., The break-off phenomenon. J. Aviat. Med. 28:121, 1957 (Author's Summary)

Individual interviews were carried out with 137 jet pilots. A content analysis of the interviews revealed that the break-off effect is a clearly defined phenomenon, although pilots are somewhat reluctant to talk about it. It is a condition of spatial orientation in which the pilot conceives himself to be isolated, detached, and physically separated from the earth so that he is no longer in contact with it. Forty-eight (35 per cent) of the pilots interviewed reported that they had experienced it, and that it is most frequently associated with three conditions of flight; flying (1) alone, (2) at high altitude, and (3) with a minimum of immediate activity required during the flight. A factor such as number of flight hours appears to be of little or no importance for the experience.

19. Cramer, E. H., Flinn, D. E., Psychiatric aspects of the SAM two-man space cabin simulator. SAM-TDR-63-27, 1963.

The authors discuss the interpersonal relationships and psychiatric problems arising in 2-man crews in the SAM chamber. Despite relative immobility and lack of opportunity for moving around there appeared to be little subjective reaction. The schedule kept the men separated physically much of the time. Perceptual aberrations although present in the one-man simulator, and sufficient to cause termination of flights, were not present to any significant degree in the two-man flight. Transient distortions occurred at least once in nearly half the subjects but were not associated with a true loss of contact with reality, nor with anxiety or disruption of performance. It would appear that despite underlying friction and hostility in individuals relatively unsuited to each other, mission goals are sufficiently important to prevent eruption of significant overt friction. Requirement to endure long periods of relatively monotonous monitoring while avoiding deleterious effects of boredom and fatigue appears to be significant and major problem, which may be aggravated in space flight by relative lack of motility and limited opportunities for diversionary and recreational activity.

20. Davenport, E. W., Congdon, S. P., Pierce, B. F, The minimum volumetric requirements of man in space. AIAA-63-250. General Dynamics/Astronautics., 1963.

20. (Cont) In an attempt to derive a method for predicting crew volume, as a function of crew size and mission duration, a working hypothesis was adopted that crew volume requirements stem from the required crew functions and activities. Such functions and activities may grow from a variety of needs.

In support of the indicated approach, an analysis of crew activities in space vehicles was performed, which indicates that activities fall into a few basic categories which are common to most systems. These basic activities included the following: (a) command and control operations, (b) systems control or station-keeping operations, (c) research or special mission operations, (d) maintenance, (e) crew personal operations, (f) crew skill maintenance, (g) locomotion, and (h) sleep.

Estimates were made of crew volumes required for the conduct of basic activities for crew sizes of 1, 3, 5 and 10; and mission durations of one day to 400 days. Some of the activities were found to require more volume growth than others. Crew size appears to be the primary determinant of volume for some activities, while for others mission duration is the more significant factor.

When combined, the volume requirements per man resulted in an increase with both crew size and mission duration. While one would tend to anticipate the need for more volume on missions of longer duration, one might not anticipate the increased volume requirement per man as crews become larger. This effect stems from function and area specialization.

21. Davis, J. M., McCourt, W. F., Courtney, J., Solomon, P., Sensory deprivation: The role of social isolation. Arch. Gen. Physch, 5:106, 1961.

Authors describe two series of experiments conducted to test the effect of social contact in a standardized sensory deprivation situation. In the first, 5 pairs of male strangers were tested, each of a pair being in his own tank-type respirator, not seeing one another, but permitted to converse. In the second, 11 married couples were tested similarly. Despite the social contact permitted, some of the effects of sensory deprivation occurred. Three subjects hallucinated in one experiment and one hallucinated in the other. In addition, the subjects experienced illusions and psuedosomatic subjective mental clouding and other emotional changes along with intellectual impairment. It would seem that the mental aberrations were not so severe as in experiments allowing no social contact. Authors quote a paper (Davis, J.M., McCourt, W. R., Solomon, P., The effects of visual

21. (Cont) simulation on hallucinations and other mental experiences during sensory deprivation. Amer. J. Psychiat. 116:889, 1960) in which meaningless visual stimulation by flashing light was given subjects in a previously standardized sensory deprivation situation. This light did not prevent the appearance of mental aberration.

Including findings from other work, it would appear that (1) social isolation itself produces none of the effects of experimental sensory deprivation (2) social contact does not eliminate mental disturbance in sensory deprivation (3) social contact lessens the effect of sensory deprivation.

22. Dempsey, C. A., VanWart, F. D, Duddy, J. H., Hockenberry, J. K., Long term human confinement in space equivalent vehicles. Presented at Third Annual Meeting of American Astronautical Society, New York, 1956. Advances in Astronautical Sciences 1-89, 1957.

This paper describes the 56 hour cockpit study carried out at the Aero Med Lab and outlines the intentions for a 5 man 124 hour study. The 56 hour study used a test facility consisting of a grounded F-84 aircraft and an observer control station. Subjects varied in stature, weight, and age, representative of the pilot population. Test was divided into three periods of 19 hours each. During first, low performance period, subject operated test equipment for 15 minutes of each hour and was permitted to sleep. Next period required high performanance in which subject operated test equipment continuously and was required to remain awake and as alert as possible. Last 19 hours was a period of low performance representing a cruise home. Three 10 minute emergency tests were given during each low performance period. Measures were made of heart rate, EEG, muscle potential, and skin resistance. Urine and blood samples were taken and fluid intake was monitored. Psychomotor tests consisted of a reaction time device working at random intervals, and a modified British clock test. Noise level of 115 db was maintained. Results indicated that cockpit was habitable for 56 hours. Hearing loss ranged from 35 to 50 db but recovery occurred within 4 days. Psychomotor tests suggested downward trend of alertness from onset of high performance period to end. GSR was highest on first day and progressively decreased.

23. Dempsey, C. A., Human Factors of nuclear powered aircraft. in Nuclear Flight, Ed. K. F. Gantz; Duell, Sloane, and Pearce, New York, 1960.

Describes the nuclear aircraft simulator at WADC with a volume of 710 cubic feet, a leisure area and work area for

23. (Cont) crew of four. Experiments of 120 hours duration indicated the cabin to be habitable with minimum stress. Most common problem arose from hostile interpersonal relationships. Performance testing revealed no deterioration.

24. Doane, B. K., Mahatoo, W., Heron, W., Scott, T. H., Changes in perceptual function after isolation. Canad. J. Psychol. 13:210, 1959. (Author's Summary)

Tests of figural after effect, color adaptation, and the after image of movement showed an increase in the after effects of stimulation following four days of sensory restriction, while tests of constancies (size and shape) revealed some decrease in effect. Visual acuity and 2-point tactual discrimination tended to improve. Experimental Ss gave poorer performance in spatial orientation tests and tactual discrimination than controls. Data for the 13 cubicle Ss and 4 ambulatory Ss, wearing translucent masks, were combined. Qualitative reports of visual disturbances (e.g., movements and surface or linear distortions and hallucinations were given by most Ss.

25. von Euler, U. S., Lundberg, U., Effect of flying on the epinephrine excretion in Air Force personnel. J. Appl. Physiol. 6:551:1954. (Author's Summary)

The epinephrine output in urine was estimated in Air Force personnel during night rest (sleep), during normal ground activity, and during flights. The epinephrine output during ground activity (6.7±0.98 mμg/min.) and during flight (24±2.7) in inexperienced air transported privates was significantly different (P= <0.001). In a group of pilots similar differences in epinephrine output during flight and during ground activity were observed. A significant difference was also noted for nor-epinephrine in the latter group. During night rest the epinephrine output was 2.2±0.65 and 5.1±0.66 mμg/min, respectively, in two groups with and without flights as passengers the following day. The former figure was significantly lower than that during ordinary ground activity.

26. Faucett, R. E., Newman, P. P., Operation Hideout. USN Med. Res. Lab. Report No. 228, 1953.

Twenty-three human volunteers were confined in the submarine USS Haddock for a period of 60 days. During the first and last 9 days they breathed atmospheric air; during the intervening 42 days they breathed an artificial atmosphere containing

26. (Cont). 20.5% O_2 and 1.5% CO_2. Before, during, and after the exposure period, measurements were made of physiological functions and psychomotor performance. No apparent attempt was made to distinguish between the effects of confinement and increased CO_2 concentration. No changes were observed in basal pulse rate, weight, oral temperature, or blood pressure during the exposure period, nor were changes observed in diurnal cycling. Pulmonary ventilation and alveolar CO_2 tension were each elevated about 8% during exposure; the former returned to control level during the first three days post-exposure. O_2 consumption was increased during first part of the exposure period but later returned to the initial level. By the 6th week of exposure, decreased sensitivity to CO_2 was evidenced by diminished ventilatory response to 5% CO_2. This decreased sensitivity was maintained up to 4 weeks post-exposure. No change was observed in erythropoiesis, but a consistent decrease was observed in total neutrophils during CO_2 exposure and 8 days thereafter, accompanied by a consistent downward trend in eosinophils. EEG indicated a reduced depth of sleep during CO_2 exposure. Serum electrolyte changes were consistent with mild respiratory acidosis. Urine bicarbonate rose after first 2 weeks to a peak at 4 weeks, followed by a fall at the end of 5 weeks, and a sharp rise post-exposure. No major psychiatric problems were encountered. Moderate increases in anxiety occurred, associated with, and proportional to, the situations encountered. No significant changes were observed in sensory and perceptual processes. No decrement was observed in psychomotor performance as measured by a large battery of tests. Problem solving, as measured by an addition test and a multiple choice test showed no marked decrement. Span of attention and immediate memory remained relatively constant throughout. Motivation, personal, and interpersonal relationships, showed a trend towards increasing slight deterioration with time, followed by improvement as termination approached.

27. Findley, J D., Migler, B. M., Brady, J. B., A long-term study of human performance in a continuously programmed experimental environment. University of Maryland Institute for Behavioral Research and Walter Reed Institute of Research, 1963.

This project was essentially the study of the effects on man of a programmed environment, but included incidentally elements of isolation and confinement. The principles and techniques of the animal laboratory were incorporated into the design of the experimental environment, whereby requirements or contingencies were programmed such that behavior of the organism produced specific changes in the environment. Particular behaviors had given consequences, but only under specific stimulus conditions.

27. (Cont). The environment differed fundamentally from a normal environment in that opportunities for various kinds of activities were available only as specifically provided for by the behavioral program. The chamber consisted of three interconnected rooms, one room 11 ft. x 11 ft., 2 small rooms 5 ft. x 5 ft. All three were 8 feet in height. Rooms were air conditioned with temperature at 75° while awake, 70° asleep. Sound attenuation was provided. The chamber was normally illuminated except during parts of the program in which lights were extinguished. A decorative appearance was provided. The main room contained a bunk, table, and chairs, a lounge chair, automatic devices and consoles along with small pieces of equipment and storage drawers. One small room was a work room and the other contained full toilet facilities. Access to the small rooms was available only on a programmed basis except for limited toilet use. All activities were introduced by outside investigators, or automatically controlled. To maintain himself, and obtain recreation and rewards, a subject was required to perform various activities in a programmed order as directed by console indicators. A subject was maintained in this environment for 152 days. Several behavioral decrements occurred suggesting a cumulative build-up of behavioral stress in the subject. These included increasing frequency of limited toilet operation, increasing frequency of general negative complaints, somatic complaints, and requests for health items, increasing frequency of sleep, increased duration of toilet operations, and eating, declining time in creative activities. Authors consider these behavioral decrements due more to social isolation than to confinement per se.

28. Flaherty, B. E., Flinn, D. E., Hauty, G. T., Steinkamp, G. R. Psychiatry and space flight. USAF SAM Rept. 60-80, 1960.

Authors review expected stresses of space flight, namely, altitude, acceleration, weightlessness, temperature, radiation, meteorites, diurnal cycling, emotional factors. They describe studies in the SAM one-man space simulator where conditions were produced to represent as closely as possible orbital flights of 36 hours to 7 days. They describe perceptual illusions and other problems occurring in three subjects and discuss the mechanisms of perceptual aberration.

29. Flinn, D. E., Monroe, J. T., Cramer, E. H., Hagen, D. H., Observation in the SAM two-man space cabin simulator. IV, behavioral factors in selection and performance. Aerospace Med. 32:610, 1961.

The purpose of behavioral studies was (1) to observe patterns of behavior emerging and identify any disruptive emotional reaction, (2) to anticipate ways of minimizing stress leading to these responses, (3) to select suitable individuals. They note that factors imposing a

29. (Cont). degree of stress on the astronaut include severe confinement and limitation of ability, relatively monotonous and unvarying environment, prolonged commitment to exacting duties, and continual threat of external hazards. Results may be distraction from important tasks, impaired morale and motivation, increased possibility of errors or faulty judgment. They discuss confinement literature, particularly two-man confinement, pointing out that the latter frequently leads to disruption in interpersonal relations. Note also that a three-man group is basically unstable, since two members frequently ally against the third. They studied the effects in four flights, (1) a two week flight at 18,000 feet, (2) four 30 day flights at 18,000 feet, and (3) one 17 day flight at 33,000 feet. Subjects received pre-flight psychiatric and psychologic assessment, inflight observation of behavior, post flight debriefing, and psychological testing. Each subject also kept a diary. Selection involved examination for overt evidence of emotional instability. Inflight behavior was observed by a closed circuit television system, and by daily scoring on Bales Interpersonal Process Analysis. Subjects in general maintained high morale and motivation and experienced very little boredom. A few auditory illusions occurred but there was no evidence of gross perceptual aberration as seen in the one man space cabin simulator. Feelings of resentment appeared among the subjects but the success of mission was sufficiently important to subjects that they consciously refrained from any disruptive behavior.

30. Funkenstein, D. H., King, S. H., Drolette, M., The direction of anger during a laboratory stress-inducing situation. <u>Psychosom. Med.</u> <u>16</u>:404, 1954.

Sixty-nine healthy college subjects were exposed to an anger provoking stress situation during which psychological and physiological responses were observed among those who vented their hostility at the examiners, those who turned it towards themselves, and those who developed anxiety.

31. Gaito, J., Bowe, R., Greco, S., Hanna, T. D., Environmental requirements of sealed cabin for space and orbital flights. Part 3. NAMC-ACEL-385, 1958.

32. Gell, C. F., Psychophysiological aspects of the multiple crew compartment study. American Rocket Society, ARS-681, 1958.

Paper begins with a short history of confinement in the U. S. Navy. Author then describes a 7 day confinement in a modified low pressure chamber, 11 x 6 x 7 ft. fitted with bunks, toilet, and sink. A water bath for heating K rations was provided, and windows were equipped with polarized glass. Six volunteers were selected from 16 available at random. Chamber was maintained at 10,000 ft., with nitrogen at 103 mm Hg and oxygen at 418 mm Hg. Blood and x-ray studies were made before and after confinement. Continuous daily urine samples were collected. Periodic pulse readings, chest expansion measurements, and vital capacity measurements were made daily. Each man had 65 cubic feet of individual space. All men remained for the full confinement. No physiological disturbances were observed. No evidence of undue psychological stress was elicited. Towards the end of the confinement, subjects became unhappy about food and odors. Full details are not presented but author claims that detailed scientific reports would be prepared.

33. General Electric Manned Space Operation. Results of a four-man 30 day mission simulation program. GE Doc. 64SD679, 1964.

Facilities comprised a four-man, 2 compartment, cabin inside a 39 foot diameter spherical space environment simulator with an airlock. Also in the complex was a rendezvous and docking simulator. Atmosphere within the simulator, and thus within the cabin, was held at 7 psi 50/50 O_2/N_2. Cabin was a cylindrical vertical shell 12.5 diameter by 16 feet long in two 8 foot sections with hemispherical ends. Configuration was based on results of previous study for a rotating station providing one artificial G. Cabin contained two rooms, a living area with 2 bunks, cooking facilities, washroom facilities, etc., and a work area. Floor area in each was approximately 63 square feet with a ceiling of approximately 7 feet. Adequate lighting and ventilation were provided along with storage for food, utensils and medical supplies, etc.. Crews were selected on basis of relevant military flying, or submarine experience, or civilian flying experience, technical civilian education, and current work assignment, superior general intelligence, strong fine psychomotor coordination, absence of potentially disabling

34. Georgia, University of., Shelter occupancy study - University of Georgia, 1962-63, Office of Civil Defense, GEOU-226-FR.

This paper describes 3 pilot studies and 4 experimental studies undertaken in the University of Georgia simulated fallout shelter.

Pilot Study 1: An instrumentation study with 10 subjects. Space 10 square feet, 65 cubic feet per person. Bunk and recreational facilities permitted along with wash water, coffee, cigarets, handbooks, manuals, etc. Duration 3 days.

Pilot Study 2: Replication of pilot study 1. 10 subjects, 10 square feet, 65 cubic feet per person, recreational facilities, no wash water, coffee, or cigarets, limited bunks. Duration 3 days.

Pilot Study 3: Very high stress variables introduced. 10 subjects, 5 male and 5 female, 8 square feet, 52 cubic feet per person, temperature high, humidity high, ventilation low, limited water, diet 370 calories per day, biscuits, chemical sanitation, no bunks, no blankets, no recreational material, no wash water, no coffee, no cigarets. Duration 3 days

Results of pilot studies showed that potential use of the shelter under these circumstances was feasible. Pilot study 3 was considered to represent the approximate limits of psychological tolerance without medical attention.

Full Study 1: This was a four day study involving 30 occupants, 15 male, 15 female, age 15 to 50, with area of 8 square feet, and volume of 52 cubic feet plus 1 cubic foot storage per person; ventilation 15 cfm per person; temperature and humidity optimal. 300 cal per person per day without additional food were provided and 1 qt. per person per day drinking water. Screened chemical toilets were available. No bunks, no blankets, recreational materials, washing water, coffee, or cigarets. Eight occupants defected during study period. Remaining occupants completed study and predicted they could endure 2 more days before feeling compelled to leave.

Study 2: Involved 15 males, 15 females, age 9 to 67, with space of 8 square feet and volume of 52 cubic feet plus 1 cubic foot storage per person, ventilation 15 cfm per person

33. (Cont) emotional conflicts, strong emotional defenses, adaptability, and high motivation. From 40 company volunteers, 28 were originally selected and reduced by psychological and medical examination to 15. Four were selected from 15. Supplies for simple medical and surgical ailments were provided and subjects were trained in their use. Only minor conditions developed during the exercise. Exterior medical monitoring was continuous. Subjects were given physiological training in order to undertake biomedical testing, including spirometry and venipuncture. Complex task scheduling was set up allowing for 7 hours sleep. Initial unsatisfactory task scheduling had to be changed after 4 days. Inflight psychological testing involved higher order mental function such as memory for digits, mental arithmetic, number retention. Reaction time, eye-hand coordination and vigilance were also measured. No significant decrements were observed during the simulation period. Rendezvous and docking techniques were also measured. Most of them were successfully completed.

Psycho-social evaluation was carried out by measures of group cohesiveness, which showed a pre-test rise followed by a during-test fall and post-test rise. Other group ratings were also carried out. Physiological testing was based on assessment of the effects of the gaseous environment, and the development and assessment of procedures and techniques which might be used during space flight. Subjects underwent $3\frac{1}{2}$ days pre-test analysis, including basic clinical studies, namely, hematology, urinalysis, blood and urine chemistry, bacteriology, ECG, chest x-ray, eye examination, and audiometry, along with spirometry, pulmonary ventilation, cardiac output, blood volume, renal clearance, and assessment of cardiovascular responses. Tests in flight included caloric intake, nitrogen balance, calcium and water balance, body weight, hardwire ECG, phonocardiogram, carotid microphone, with blood pressure and temperature measures. Other tests included spirometry and exercise tolerance. Samples of urine and blood were obtained for chemistry and bacteriology. Nitrogen and water balance showed significant trends; calcium balance was positive; catecholamine excretion correlated with stress. A loss in exercise tolerance was observed and was coupled with a clinical impression of reduced muscle tone. An initial drop in vital capacity was observed followed by a return to normal. Bacteriological studies showed transfer of a hemolytic staphylococcus aureus from a nose culture to two other subjects.

34.. (cont) temperature and humidity optional. Restricted food (789 calories per person per day), restricted water, ($1\frac{1}{2}$ qts.), chemical toilet; sleeping on thin cardboard placed over concrete floor. No bunks, no blankets, no recreational supplies, no bathing water, no coffee, 1 package of cigarets per smoker, 5 occupants defected during study. Duration 14 days.

Study 3: This was a two week study involving 15 males and 15 females, age 7 to 66, with living space of 8 square feet, 52 cubic feet plus 1 cubic foot storage, food 814 Cal per person per day, water 1 qt. per person. No bunks, no blankets, no coffee, no wash water, 1 package cigarets, no watches, no recreational materials other than children's crayons and school texts. Two occupants defected.

Study 4: This was a one week study involving 28 children, age 7 to 12 and two adults. Living space was 6 square feet, 39 cubic feet, per person plus 1 cubic foot storage. Temperature and humidity were optimal, ventilation 40 cfm per person during day, 15 cfm per person during night. Food 600 Cal. per person per day plus 300 Cal carbohydrates supplement. No bunks, no blankets, no recreational materials, no washing water provided. 11 children and the shelter manager defected during the study.

Few physiological findings are reported. Medical complaints including headaches, nausea, colds, skin rashes, weight loss 4 to 6 lbs. occurred in all studies. Environmental complaints included bathing facilities, sleeping conditions, odors, chemical toilet, temperature and ventilation. Complaints regarding available space were minimal.

35. Gerathewohl, S. J., Work proficiency in the space cabin simulator. Aerospace Med. 30:722, 1959.

Author describes two tests in a simulated space cabin, the first being conducted in the SAM one-man cabin with a total volume of 96 cubic feet, of which almost half was filled with instruments necessary for maintaining atmosphere of 380 mm Hg pressure and 40% oxygen. The other was conducted on two subjects acclimatized to high altitudes in a 212 cubic feet sealed cabin under temperatures varying between 26 and 36° C with an average of 29.5°. Cabin altitude range from 13,000 to 17,000 feet during the test. Work proficiency was tested by the Kraepelin addition test, which required continuous adding of single digits.

35. (Cont) The number of additions made daily increased steadily during the stay in the cabins, along with the error and correction scores. Individual subjects became more irritable as time progressed, but they retained learned and useful behavior. The test required continuous discrimination, recognition, and reading, of at least three single digits per second.

Author notes that subjects were engaged in purposeful activities and well informed about the situation and considers that this contributed to their ability. Similarly the ability to learn through practice is not impaired if physiologic minima are secured. Daily performance increased despite the considerable changes in composition of atmosphere, temperature and relative humidity. Likewise, lack of appetite, extensive sweating, insomnia, irritability, and loss of weight did not markedly impair the individuals' mental efficiency. Motivation for taking the test was maintained and even increased during the course of the experiments.

36. Goldberger, L., Holt, R. R., Experimental interference with reality contact. (Perceptual isolation). J. Nerv. Ment. Dis. 127:99, 1958. (Author's Summary)

Fourteen paid college student volunteers spent eight hours lying in a semi-soundproof room, audition and vision being dominated by patternless steady inputs. Aspects of intelligence, as measured by simple auditory tests before and during the last minutes of isolation, showed no consistent impairment but Ss performed significantly worse on more complex reasoning tasks given immediately after isolation. Spontaneous verbalization, recorded and analysed, indicated: A general feeling of decreased efficiency and continuity in thought, affective disturbances, fantasy, often with direct drive content, general increase in the vividness and frequency of imagery (visual and auditory) disturbances in time sense, and miscellaneous other effects.

37. Gorbov, F. D., Myasnykov, V. I., Yazdovskiy, B. I., Stress and fatigue under isolated conditions. FTD-TT-63-1015, 1964. Air Force Systems Command, Wright-Patterson AFB, Ohio.

This paper summarizes Russian work with subjects confined for 10 to 15 days in the limited and closed

37. (Cont) space of a special chamber. Conditions included solitude, lack of 2 way speech communication, and near isolation from external light, sound and other stimulation. Motor activity was not restricted. Length of sleep was 9 hours daily. Subjects ate four times daily with 5 to 6 hours between meals. Standard normal environmental conditions were maintained. Measurements included bipolar EEG with flashing light, EMG, GSR, potential difference between palmar and dorsal surfaces of left hand, respiration, pulse. Behavior was also monitored by visual and remote observation. Psychological testing using the black and red square technique was used. Changes were observed in the EEG, including decrease in biopotential amplitude, appearance of slow diffused rhythms on the initial curve of the EEG before the light stimulus, decrease of cortical reactance and excitability. Latency of EMG motor response increased by average of 120 msec by end of the experiment. In psychologic testing, the "level of the prescribed activity" decreased in second half of test. Major effects were noted 6 to 8 days after onset of isolation. The amount of 17-ketosteroids excreted with urine decreased at this time, indicating loss of tolerance of the organism to adverse conditions.

38. Grodsky, M. A., Bryant, J. P., Crew performance during simulated Lunar Mission. Martin Space Systems Division, Baltimore., MAR-ER-12693, 1962.

This paper describes 2 pilot studies and one 7 day simulation of a Lunar orbital, landing, rendezvous, and return flight. Authors note two major factors in prolonged space flight, namely, reduced spatial volume, and long duration of abnormal sensory environment. Note that crew tasks for Lunar mission form three general categories, namely, flight control tasks, system monitoring and management tasks, navigational tasks. Note also that confinement and sensory deprivation literature indicates the occurrence of shifts in internal norms in detection of stimuli, perceptual disturbances, inability to perceive relevant stimuli, loss of logical reasoning in complex tasks, personality changes and bizarre behavior, stimulus hunger, possible loss in motivation. Suggest that these findings may not be applicable to well motivated experienced astronauts. Note that studies on well simulated space mission tend to indicate

38. (Cont) less bizarre behavior and personality effects. Motivation of crews is an important variable and effects of duty cycle are probably as important as confinement or sensory deprivation. Rationale of authors' studies required use of dynamic performance tasks corresponding to flight control phases, use of realistic representations of system and navigational tasks, use of various duty cycles, use of various physiological measures as indices of reaction or tolerance.

Studies undertaken consisted of pilot orientation, pilot training (physical conditioning, medical evaluation, task training), and collection of pre-flight baseline data, over a 12 week period. Three simulated flights were conducted, two of 75 hours, and one of 168 hours. Two duty cycles (24 hour, 26 hour), were used in first two flights on basis of which a 26 hour cycle was selected for the 168 hour flight. Crew members were NASA test pilots with extensive experience. Simulator comprised the main vehicle and an excursion vehicle. Main vehicle (400 cubic feet) included flight deck, sleeping area, off-duty area, toilet, maintenance and response area, and galley. Variables measured to evaluate performance included flight control tasks, system tasks, detection of malfunctions, navigational tasks, behavior response tasks, duty cycle, displays and internal configuration, physical condition, 17-OH ketosteroids, psychological evaluation, medical evaluation, analysis of taped data, and general physiological data. Behavioral tasks included time estimation and reaction time, performance by crew during flights. Physical conditioning consisted of number of repetitions of specific exercises. 17-OH ketosteroids were compared with 48 hours of pre-flight baseline data. Psychological evaluation was by Rorschach and psychiatric interview. Medical evaluation comprised physical examination and Harvard step tests. General physiological data included blood pressure every 6 to 8 hours and diet evaluation.

Analysis was made of all performance parameters. Results of flight 1 indicated no direct effect due to duty cycle. All examiners reported crew appeared fatigued due to lengthy hours of duty time at end of flight (e.g., engineer 22 hours). Crew indicated long sustained duty periods (excess of four hours) made monitoring difficult. Flight 3 results indicated no direct effect upon crew performance due to duty cycle,

38. (Cont) also no evidence of fatigue. At the same time there was no evidence of adaptation to the duty cycle at the end of 7 days. Authors note that the effect on performance might have been disguised by high motivation and skill. Reaction time data indicated no differences in any flight as compared with controls. Also no differences observed in time estimation. This is in contrast with artificial confinement studies, perhaps because subjects had a consistent keen awareness of time not effected by the situation. OH ketosteroids analysis in two subjects showed no variation other than that associated with diurnal cycles. A third subject showed variation perhaps related to geographical change in diurnal cycle. Blood pressure changed little during the flight and did not yield any indication of stress. Diet for flights 1 and 2 was 1800 calories and for flight 3 was 1500. It was well prepared and enjoyable. Average loss of $1\frac{1}{2}$ lbs. per man was observed in flights 1 and 2. In flight 3, loss varied from $6\frac{1}{2}$ to 9 lbs. No detectable loss of physical conditioning was observed nor changes in Harvard step test, as measured by number of steps and by pulse rate. No back or cervical pain observed associated with reduced spatial volume. No indication of extraneous motor movements described as "stimulus hunger". Crew considered exercise valuable. Purpose of exercise was to maintain endurance rather than strength. No abnormal findings were observed on medical examination, other than slight fatigue. Psychological evaluations showed some loss of creativity and increase in irritability after flight 1, along with general loss in reaction time. Results after flight 3 showed improvement over flight 1. General psychological conclusions were that length of flight (up to 7 days) does not appear to be factor in precipitating disturbance in personality or social spheres. During flight no occurrence of bizarre behavior, intense hostility, gross desocialization, or personality disturbances were observed. Crew seemed well motivated, responded well and appeared friendly.

Some loss of performance was observed in system and navigational tasks but was attributed to lack of practice and not to spatial confinement.

39. Gussow, Z., A preliminary report of Kayak-angst among the Eskimo of West Greenland. Int. J. Soc. Psychiat. 9:18, 1963.

Author describes 13 cases of a naturally occurring form of sensory deprivation among the Eskimos of West Greenland, known as Kayak-angst, meaning Kayak phobia or Kayak dizziness. It also occurs in the polar Eskimo and in East Greenland, but apparently not among other Eskimos. It occurs typically when male hunters are alone on a calm sea or lake with minimal sensory input. It is characterized by hallucinations, anxiety, or even panic. The sensation generally terminates upon reaching land or with the arrival of help. Post attack symptoms may occur, including headaches or somatic complaints. Fatigue and emotionally upsetting experience tend to increase vulnerability. It has also been observed in Europeans with Kayak experience.

40. Hall, C. E., Isolation and sensory deprivation. in Physiology of Man in Space. Ed., J.H.U. Brown, Academic Press, New York and London, 1963.

Author notes that in a space cabin the occupant is deprived of companionship, exchange of thoughts, exercise facilities, outlet for relaxation, and diminution of sensory stimulation. This leads to irritability, boredom, fatigue, and hostility, with decrease in efficiency, reliability, motivation, and competence. Duration of exposure prior to onset of signs and symptoms, the particular form the latter take, the rapidity of deterioration of psychological conditions, and the persistence of effect after return to normal are all subject to individual variation. Effects may persist for many days after return to normal environment.

41. Hanna, T. D., A physiologic study of human subjects confined in a simulated space vehicle. Aerospace Med. 33:175, 1962.

This study reports some of the physiologic findings from 6 men confined in the Navy simulated space cabin for 8 days at sea level, rebreathing their own expired air by a closed cycle oxygen regenerating system. Chamber allowed approximately 75 cubic feet per man. Subjects were selected on basis of physical health and psychometric tests to provide a group of healthy young men possessing physical characteristics similar to those one might expect to find in an operational setting. Measurements were obtained from each subject while on duty at the "Vigilance" work station, selected as the most stressful since each subject was lead to believe that he was among other things controlling oxygen supply for

41. (Cont) himself and others. Measures included heart rate, respiration rate, forehead skin temperature, skin conductance. Records were obtained by a bioelectric harness and an oxygen mask. All data were subjected to analysis of variance. All indices had a high initial value. By day 2, 3, and 4 all values decreased from day 1 as adjustment to the new environment occurred. Introduction of an emergency on day 5 resulted in a sharp increase in the values of all variables. Variables fell again on day 6 but remained above the values on days 3 and 4. Heart rate and norepinephrine excretion continued to drop on day 7. Respiration rate and skin conductance exhibited slight rises. Latter findings probably represent anticipation of termination of experiment. Changes in body weight were varied. One man gained one pound during 8 days while two of the men lost four pounds. Individual weight figures are not provided but mean net change in weight of 6 men was a loss of 2 pounds over 8 days.

42. Hanna, T. D., Burns, N. M., Tiller, P. R., Behavioral and physiological responses to varying periods of sensory deprivation. NAEC-ACEL-490, 1963.

Six volunteer Naval enlisted men were randomly confined under conditions of reduced stimulation for periods of 4, 8, 12 and 24 hours in an isolation chamber measuring 4 x 8 x 6 feet. Subjects lay on a Mercury type couch and, because of bioelectric wires, etc., were unable to turn over or to get off the couch during the session. A bottle was provided for urine collection. Food was supplied as a box lunch, along with ice water and chilled fruit juice. Cabin was unlit except for low voltage red light when required, and was nearly soundproof. An audio communication system was available but used only for test purposes. Physical and psychological screening was given to the subjects. Heart rate and conductance were measured at regular intervals during the confinement, along with occasional EEG, respiration rate, and blood pressure. Psychological tests, including presentation of amorphous figures, time estimation, digit span, sentence completion, draw-a-person, were presented towards the end of each session followed by an interview at the end of the session. Results, including statistical analysis, indicated that the parameters sampled were influenced both by the altered sensory environment and by factors inherent in individual personalities. Sources of variance could be attributed to personality differences among subjects, although length of deprivation was not an

42. (Cont) overall dominant source of variance. Certain response systems appeared more sensitive than others. Thus, performance on digit spans was not appreciably altered whereas systematic changes occurred for the estimation of time intervals and for the draw-a-person technique. In time intervals, in control sessions, a 15 second interval was slightly over estimated whereas the other 4 time intervals (30, 90, 180, and 300 seconds) were moderately to greatly underestimated. For the 4 experimental periods, 15 second interval was greatly overestimated, 90 second interval moderately overestimated, 300 second interval moderately underestimated; 30 second interval varied from slight to great overestimation, and 180 second interval varied from slight to moderate underestimation. Heart rate in general decreased, modified by diurnal variations. Skin conductance varied. No trend in frequency or amplitude of EEG potential was observed. Blood pressure in one 12 hour session decreased with time for about 5 hours and thereafter remained steady. Respiration similarly decreased with time and then remained steady.

43. Hanna, T. D., Gaito, J., Performance and habitability aspects of extended confinement in sealed cabins. Aerospace Med. 31:399, 1960.

Authors note that although man has survived long term confinement in relatively small spaces, he has not been required to exhibit high level precision performance. Authors describe a study (see Hendler) in which 6 men were confined 7 days at 10,000 feet. Cabin contained 3 work stations; a leisure area, containing 2 bunks, 27 x 62 inches, a flush type toilet, individual urinals, a collapsible wash basin, small bench attached to wall, and a table in the center of the chamber. Storage shelves, and small bins were available. Total floor area of entire confinement chamber, leisure area, and work area, was 70 feet, 38 and 35 square feet respectively. Total free area was 33, 18, and 15 square feet, while volumes were 448, 211, and 237 cubic feet respectively, or about 75 cubic feet per man. Decorative devices were used to provide a feeling of space. Performance tasks included simple routine psychomotor tasks, simple judgment functions, and auditory task which involved processes of learning, thinking, and reasoning. Tasks were intended to represent those at aircraft stations. A total of 10 performance tasks were run, along with an intellectual aptitude test before and after the run.

43. (Cont) After the run a questionnaire was completed and diaries were examined. 24 hour work schedules were set up with subjects working in pairs.

Authors note that laboratory simulation cannot compare with the full experience of space. Within the frame of reference, however, the results of the experiment appear to indicate that intellectual functions of subject should not deteriorate over a 7 day period, even when environment conditions are not optimum. Performance on 7th day was as effective as on the first day in the complex tasks. Variability on the performance of the simple psychomotor tasks probably represented boredom. Performance might have been better had the tasks been less simple. An effect of diurnal cycling on performance was observed. Authors suggest that any deviation from optimum conditions would tend to be magnified with increasing time in the confinement area.

44. Hartman, B., Flinn, D. R., Crew structure in future space missions. Presented at the 5th Annual Lectures in Aerospace Medicine, 1964.

This paper says little about confinement per se. It analyzes job requirements and crew number in space situations and provides a very good review of the small group literature. It also describes some space cabin studies with the SAM simulator, including four-man simulated space flights. Concludes that, despite minor irritations, well motivated crew members are capable of supressing antagonistic feelings in interest of mission completion, and continue to function without adverse effect upon performance. Although interpersonal problems may occur in a small crew as mission time is extended, it appears likely that any such problems will not be of major magnitude. As crews become larger, even brief missions may result in interpersonal problems.

45. Hatch, H. G., Algranti, J. S., Mallick, D. L., Ream, H. E., Crew performance during real-time lunar mission simulation. NASA-TN-D-2447, 1964.

In order to study the performance of a crew in prolonged space flight, a simulation was made of a lunar landing mission beginning with launch from earth and terminating after earth re-entry. Three trained test pilots, enclosed in two interconnected mock-ups of a command module and a lunar orbit rendezvous vehicle, flew three realistically simulated missions. Piloting performance was

45. (Cont) evaluated by comparison of accuracies achieved during the simulated missions with the baseline data obtained during training. The areas evaluated included crew proficiency in normal mission duties, crew alertness to emergency situations, the effects of duty cycles and physical conditioning, and crew psychophysiological reaction. The study showed no decrement in performance of mission tasks with test pilot personnel for confinement periods up to 7 days and the alertness of the crew remained high throughout the mission. It was found that a 26 hour duty cycle with two 4 hour sleep periods was more desirable than a 24 hour duty cycle with one 8 hour sleep period. Because of the onboard exercise program, there was no deterioration of physical condition. Also, medical and psychological tests indicated no psychophysiological stress reaction due to the confinement during the 7 day mission time.

46. Hauty, G., Sensory deprivation. in Bioastronautics, Ed., Schaeffer, K. E., The MacMillan Co., New York, 1964.

Author describes problems of sensory deprivation and quotes widely from tapes made with subjects in the SAM experimental chamber. He notes the appearance of hallucinations, distortions of perceived reality, and illusions. Concludes that the joint effects of sensory impoverishment and prolonged continuous monitoring will effect aberrant behavior, and suggests that despite prior knowledge, such behavior can act to compromise the functional integrity of the operator. One subject, despite knowledge of reports by earlier subjects of aberrant experiences, did himself experience and report highly aberrant phenomena. At the same time subjects learned to terminate those aberrancies most disturbing to them by initiating behavior that has the effect of promoting diversity of sensory events, or increasing sensory output.

47. Havens, D. E., Presentation at ASME conference, Los Angeles, 1965.

After preliminary pilot studies, four selected volunteers were confined for 30 days within a simulated orbiting laboratory. Full details of the experiment are not available. The simulator allowed approximately 250 cubic feet per man in an atmosphere of 50% O_2 and 50% N_2 at 7 psi. Performance tests, psychological evaluation,

47. (Cont) exercise tolerance, pulmonary function, and biochemical tests were conducted. No abnormalities were observed. The environment involved a semi-closed system with careful monitoring of toxic contamination. An increase in the aldehyde level caused alarm at one point. It was later attributed to impairment of the waste disposal system.

48. Hawkins, W. R., Hauty, G. T., Space cabin requirements as seen by subjects in the space cabin simulator. Reports on Space Medicine, 1958, Air University USAF, SAM, 1959.

Comments concern the one-man space cabin simulator with internal dimensions of 96 cubic feet, of which half is taken up with equipment, instruments, etc.. In addition to information obtained elsewhere, subjective responses are quoted. Oppressiveness of time increased in ratio directly proportional to the duration of flight. Intermittent periods of depression are routinely observed in all subjects. At about midpoint, subjects showed a heightened sense of irritability and overt hostility that gradually increased in severity. Trivial things assumed greater significance, e. g., haphazard storage, clicking noises of camera, repetitive music, fixed position of the seat, electrodes, andparticularlythe MC-3 partial pressure suit. Work problems became boring, and when fatigued, subjects found it difficult to keep from dozing. A structural recommendation included the necessity for a place for everything and everything in its place. Seat should be adjustable to any desired position, should be contoured and convertible into a bed. Personal hygiene assumes great importance and adequate facilities to meet it should be provided. Odors become a problem and should be removed. Personal protective equipment is cumbersome and stressful. Shirt-sleeve operation is more desirable.

49. Helvey, W. M., Effects of prolonged exposure to pure oxygen on human performance. Republic Aviation Corp., RAC-393-1, 1962.

Four groups of six men each were selected to live in an altitude chamber for a two-week period. Three of the groups lived in an oxygen environment at total pressures of 3.8 psi, 5.0 psi, or 7.4 psi, and a fourth group served as a control in a sea level (14.7 psi) environment of air.

49. (Cont). Detailed medical, physiological, hematological, biochemical, microbiological and psychological studies were conducted on all subjects.

The subjective health and morale of the groups remained high. There was no evidence of cardiopulmonary impairment. Biochemical and microbiological examinations were within normal limits, although some shift in the balance of skin and fecal microflora were observed. Aero-otitis, substernal discomfort, coughing, and eye irritation caused minor intermittent difficulties. Abnormal microscopic findings in the urinary sediments were common among the oxygen exposed subjects. All subjects after exposure to 100% oxygen atmospheres at reduced pressure exhibited hematological abnormalities, some of which have persisted. Although no deterioration of general mental, sensory, or motor performance was demonstrated during the study, these abnormal findings may represent potentially serious or disabling processes over periods of longer duration or in combination with other stresses of space flight. The causes of these findings are considered to be due to either a high level of oxygen, the absence of nitrogen, or a combination of these factors.

50. Hendler, E., Mancinelli, D. A., Environmental requirements of sealed cabins for space and orbital flights. Part I. NAMC-ACEL-383, 1958.

This paper describes a study to evaluate performance and some psychological factors in volunteers confined in a chamber at 10,000 feet equivalent. An altitude chamber was modified to provide a work compartment of 448 cubic feet total and a leisure compartment of 211 cubic feet. A 10,000 foot equivalent atmosphere was maintained with 55% oxygen sea level equivalent, giving an 80% oxygen concentration at 10,000 feet. Six volunteer Naval enlisted men were confined for 7 days. Modification also included installation of decorative walls and ceilings, bunks, tables, food heater, etc. Temperature levels were set by the chamber occupants. No attempt was made to control relative humidity. Average temperature in the work compartment was approximately 74° F and average relative humidity 80%. Average temperature in leisure compartment was approximately 65° F, and relative humidity 70%. To evaluate performance, special work stations were set up within the chamber and tasks performed. Tests were administered to subjects before and after the run and comments were included in a private

50. (Cont) diary and reviewed after the run. Measures of vital capacity, respiration rate, pulse rate and urinalysis were made at intervals throughout the run without disturbing the isolation of the subjects. Complete physicals were undertaken before and after the run. Subject interviews indicated that high relative humidity became very uncomfortable and that body waste and food odors became nearly unbearable towards the end of the experiment.

51. Heron, W., The pathology of boredom. Scientific American 196:52, 1957.

Author describes the McGill experiments in sensory deprivation. Purpose was not to cut subjects off from any sensory stimulation but to remove patterned or perceptual stimulation. Experiments showed that prolonged exposure to monotonous environment has deleterious effects evidenced by impairment of thinking, childish emotional responses, disturbance of visual perception, occurrence of hallucinations, structured and unstructured, changes in the EEG manifested by occurrence of slow sleep waves and general slowing of frequencies.

52. Heron, W., Doane, B. K., Scott, T. H., Visual disturbances after prolonged perceptual isolation. Canad. J. Psychol. 10:13, 1956.

Three observers were kept in a monotonous sensory environment for six days. On returning to a normal environment, they experienced the following perceptual disturbances: (1) there was fluctuation, drifting and swirling of objects and surfaces in the visual field; (2) the position of the objects appeared to change with head or eye movements; (3) shape of lines, and edges appeared distorted; (4) after-images were accentuated; (5) colours seemed very bright and saturated, and there seemed to be an exaggeration of contrast phenomena.

53. Hicks, S. A., The effects of four hours confinement in mobile armored personnel carriers on selected combat relevant skills. AHEL-TM-3-60, 1960 (a).

54. Hicks, S. A., The effects of eight hours confinement in mobile armored personnel carriers on selected combat relevant skills. AHEL-TM-17-60, 1960 (b)

The vehicle used in this study was the M113 APC of unstated volume. (Note: Jones and Prince (1964) claim volume to be 280 cubic feet). 48 enlisted men, 4 squads of 12, were confined for periods of 8 hours in the continuously moving vehicle. Pre-confinement measures were made of performance on (a) obstructed run course, (b) rail walking course, (c) grenade throwing course, (d) rifle firing course. Pre-confinement auditory acuity as measured by response to a 4,000 cps note was also measured. Each squad participated in two experimental tasks but no squad was confined to the APC twice during the same week. All trials were given on successive days at approximately the same time. During the confinement the driver was instructed to open the vehicle only in the event of mechanical trouble or physical injury. Post confinement repeat of the pre-confinement tests which were designed to measure stamina, eye-arm coordination, gross motor coordination, arm steadiness and rifle accuracy, showed decrements in rail walking, obstructed running, and grenade throwing. No loss of hearing was observed at the 4,000 cps level. Complaints were made of severe cramping, nausea, (30%), and one claustrophobic reaction.

55. Hicks, S. A., The effects of 12 hour confinement in static armored personnel carriers on selective combat relevant skills; Study III. AHEL-TM-1-61, 1961 (a).

Vehicle in this study was an M113 APC in a stationary mode. Subjects were 40 enlisted men divided in four squads of 10 each. Pre-confinement measures were made of performance on the obstructed run course, rail walking course, grenade throwing course, rifle firing course. Since previous decrement had been noticed in presence of vehicle movements and mechanical noise, this study was undertaken in the absence of these. It was also intended to measure conditions with the engine normally idling and to measure conditions with the squad active on sensory tasks, e.g., map reading, watch keeping, telephone operation, log keeping, counting, and also inactive. The idling engine, however, provides ventilation and in its absence the internal temperature rose to an effective temperature

55. (cont) of 100^{o} within 5 hours. Consequently this portion of the experiment was terminated. Results in the idling conditions showed significant loss in equilibrium (rail walking test), significant loss in stamina and locomotor coordination (obstructed run test) observable decrement in grenade throwing accuracy; no observable change in rifle accuracy. No distinct differences appeared to be associated with the level of activity. Since effects occurred without motion, noise, or vibration, they would appear to be primarily due to confinement per se.

56. Hicks, S. A., The effects of twenty four hours confinement in mobile armored personnel carriers on selected combat relevant skills. Study V. AHEL-TM-23-61, 1961 (b). (Author's Summary).

This investigation is the fifth in a series designed to determine changes in general combat relevant performance as a result of sustained confinement in armored personnel carriers (APC's). The purpose of this investigation was to determine changes in performance as a result of 24 hours confinement in mobile APC's. Forty-four enlisted men were tested before and after confinement on tests designed to measure stamina, eye-arm coordination, locomotor coordination, equilibrium. and hand-arm steadiness. The 24 hour confinement period resulted in a statistically significant loss in eye-arm coordination and hand-arm steadiness (marksmanship). Recommendations are included for future research.

57. Hicks, S. A., The effects of twenty-four hours of confinement in mobile armored personnel carriers on selected combat relevant skills. A follow-up. AHEL-TM-7-62, 1962. (Author's Summary).

This investigation is the sixth in a series designed to determine changes in general combat relevant performance as a result of sustained confinement in armored personnel carriers (APC's). The purpose of this investigation was to determine changes in performance as a result of a confinement period of 24 hours duration. Forty-four enlisted men were tested before and after confinement on tests designed to measure stamina, eye-arm coordination, locomotor coordination, equilibrium, and hand-arm steadiness. The 24 hour confinement period resulted in statistically significant losses in all areas excluding eye-arm coordination (grenade throwing accuracy).

58. Hicks, S. A., The effects of repeated confinement on the performance of men in a temperate environment. Human Engineering Lab., Aberdeen Proving Ground, Maryland, AHEL-TM-11-64, Aug. 1964. (Author's Summary).

This investigation is the eighth in a series designed to determine changes in general combat relevant performance as a result of sustained confinement in armored personnel carriers. The present study examined the effects of repeatedly confining a single group of subjects for a 12 hour period on each of five successive days. Ninety enlisted men took tests measuring equilibrium, stamina, gross motor coordination, and marksmanship. There were statistically significant losses in all areas after the initial confinement period. Subsequent confinements showed progressively smaller decrements until, at the end of the final (fifth) session, the subjects performed at the pre-confinement level. It was concluded that repeated exposure to confinement produces an adaptation phenomenon which voids the obviously transient effects that accompany intermittent exposure. The results of this study support those of a previous study in a hot-wet environment. Recommendations for future research are included.

59. Hicks, S. A., Vehicle confinement studies. U.S. Army Ordnance Human Engineering Lab., 1964.

This paper summarizes the work described in Parts I and IV of the other vehicle confinement study papers. It states nothing new except perhaps that the magnitude of the observed decrement did not appreciably increase with lengthening increments in the periods of confinement.

60. Jones, E. R., Prince, A. I., Man's function in military space systems. McDonnell Report A-507, 1964.

As part of a general analysis on the subject, the authors reviewed 37 studies on the behavioral aspects of confinement, including the use of experimental chambers, simulated vehicles, and operational vehicles. They prepared a plot of crew free volume as a function of mission duration, identifying areas of impairment in performance and broad areas of tolerance. Noted that conditions in smaller vehicles might be more tolerable in weightless environment. They listed factors limiting habitability and made suggestions for reducing or eliminating decrements in performance. On the basis of a three-point rating scale

60. (Cont). they noted that as mission duration increased from 3 hours to 83 days, required volume per man increased from 25 to 1800 cubic feet. Up to 5 days, performance and physiological rating vary from severely degraded to near satisfactory. Beyond 5 days both ratings level off at a moderately degraded level, even though volume continues to increase, suggesting that when duration reaches a certain point further increases in volume do not improve performance. Up to 30 days, a volume of 100 cubic feet per man or more results in a satisfactory physiological and performance function. General conclusions were: a) volumes per man below about 40 cubic feet can produce severe degradation; b) studies on simulated vehicle indicate volumes per man between 45 and 90 cubic feet are borderline for up to 5 days and may cause difficulty for longer duration; c) volumes between 100 and 200 cubic feet per man satisfactory up to 30 days although they have not been tested operationally; d) factors other than volume, probably associated with isolation, appear to be prime determinates of habitability for missions beyond 30 days.

Negative effects of confinement interact with sleep and loss of rest to exacerbate performance decrement. Effects can be overcome by appropriate work-rest schedule (note studies of Adams and Chiles).

Laboratory studies have shown that a monotonous environment, limitations on movement, and repetitious motor tasks have effects similar to fatigue and sleep loss. These can be counteracted for short missions (up to 30 days) by good cabin design, adequate space per man, and rotation of crew tasks.

This paper includes valuable tables and graphs, and a comprehensive appendix summarizing the findings in 37 studies.

61. Kinsey, J. L., Psychologic aspects of the Nautilus transpolar cruise. U.S. Armed Forces Med. J. 10:451, 1959.

This paper discusses maintenance of morale during the 96 hour cruise of the Nautilus underneath the North Pole. Environmental conditions included oxygen concentration average 20%, CO_2 level below 1.5%, temperature 72 to 76 $^{\circ}$F, humidity 40 to 50%. Emergency air breathing system was available. High morale was attributed to

61. (Cont) confidence in ship, crew, and outstanding leadership. Conditions of a reasonable comfort were maintained, with the assistance of music, entertainment, and a wide variety of reading material. Author discusses the psychology of humor in maintaining morale.

62. Law, P., Personality problems in Antarctica. Med. J. Austral. 2:273, 1960.

Author describes the problems of personnel selection, dispatch, and the ensuing analysis of 30 antarctic expeditions over a 12 year period. He notes the advantages of isolation as being a) social simplicity, b) freedom for dedicated work, c) gratification. He points out that the main stresses are psychological and result from interpersonal relations. Handling of problems is improved by intelligence and education. Leadership is the most important single factor in determining group response.

63. Lamb, L. E., Johnson, R. L., Stevens, P. M., Welch, B.E., Cardiovascular deconditioning from a space cabin simulator confinement. Aerospace Med. 35:420, 1964(a).

Authors note that simulation of weightlessness includes elements of confinement or inactivity. They discuss cardiovascular deconditioning that occurred in the SAM space cabin simulations. 36 healthy male subjects had pre- and post-confinement studies of cardiovascular integrity. 26 of these subjects were actively doing instrument performance tests or carrying out other tasks. They were frequently seated, had regular sleep periods, but physical activity was limited. The gaseous environment was not uniform. Diet was carefully controlled. Each subject had a comprehensive pre- and post-flight history and physical examination. Majority had pre- and post-flight body weight determination. Serum cholesterol was available in certain instances. Study also included single pre- and post-confinement hemoglobin, hematocrit, RBC, blood volume, plasma volume, and red blood cell mass. A double Masters test was undertaken pre- and post-run. Treadmill studies, and in some cases maximum oxygen consumption, were available. All subjects had pre- and post-confinement tilt table studies which included heart rate, blood pressure and observation of syncope. Results showed that 7 subjects had increase in body weight; 6 had no change in body weight, and 19 had a weight loss of 1 to 9 pounds. Subjects showing a weight gain were very young subjects and perhaps consumed a different diet.

63. (Cont) Serum cholesterol was decreased in 16, unchanged in 3, and increased in 4. There was a direct relationship between weight loss and decrease in cholesterol. Hemoglobin was decreased in 22, unchanged in 2, and increased in 2. In one of the latter subjects the findings were probably inaccurate. Hematocrit was increased in 1, unchanged in 3, and decreased in 28. RBC was increased in 1, unchanged in 3, and decreased in 23. Blood volume was decreased in 15, and increased in 2. RBC mass was unchanged in 1, increased in 2, and decreased in 14. Plasma volume was decreased in 12, and increased in 5. Following confinement, subjects undergoing Masters tests showed a significant increase in heart rate after exercise as compared to pre-confinement. Time required to reach heart rate of 180 to 200 on the treadmill decreased in 21, remained unchanged in 4, and increased in 7. Increase was minimal. Greatest change was noted in subjects confined for 30 days. Maximum oxygen consumption was increased in 1, unchanged in 3, and decreased in 12. Tilt table tests showed a general decrease in orthostatic tolerance for the group. There was a greater increase in the occurrence of syncope. In general, subjects presented a picture of cardiovascular deconditioning. Thus, marked cardiovascular deconditioning can occur in the presence of normal G application. The influences of G diminution or absence of vertical G cannot be determined without adequate consideration of the influence of physical inactivity. The significant factor in the deconditioning is the amount of physical activity the subject is undergoing. Author suggests the severity of the clinical picture likely bears a direct relationship to the degree and duration of the immobilization. When a body cast and strict immobilization are used change noted may be more marked. If period of confinement and restricted activity is extended over sufficiently long period of time the evidence of deconditioning will be more apparent. Lesser degree of restricted activity produces similar but less marked manifestations.

64. Lamb, L. E., Johnson, R. L., Stevens, P. M., Cardiovascular deconditioning during chair rest. Aerospace Med. 35:646, 1964 (b).

To determine the physical deconditioning effects of inactivity in the $1G_z$ environment 6 healthy subjects were exposed to continuous chair rest for a period of 4 days. Prior to the experiment, weight, hemoglobin, hematocrit, and RBC were determined and orthostatic tolerance was evaluated by a tilt table response. Each subject was then placed in

64. (Cont) an overstuffed chair tilted slightly back so that angle of inclination was such that subject would lean against back of chair for body support. He was restrained in the chair and not allowed to move except for hygienic purposes. Normal Air Force rations were provided. He was allowed 8 hours bed rest daily. In the morning of the 5th day the tilt table test was repeated, and RBC count, hematocrit, hemoglobin, and body weight were determined. No subject had any adverse circulatory response or clinical symptoms during initial tilt table testing. During post test tilt table 5 subjects had clinical difficulties. These included discomfort, dizziness, nausea, faintness, vomiting, and full orthostatic collapse. Decreased pulse pressure, and increased heart rate were noted in 5 of 6 subjects. Body weight increased in all 6 subjects. Minimal evidence of hemoconcentration was indicated by increase in hemoglobin and hematocrit in all 6 subjects. This study indicates that physical inactivity alone, even in the $1G_z$ environment apart from weightlessness, or simulated weightlessness, is capable of producing extensive alterations in cardiovascular dynamics as measured by orthostatic testing in normal healthy subjects.

65. Lebedinskiy, A. V., Levinskiy, S. V., Nefedov, Y. G., General principles concerning the reaction of the organism to the complex environmental factors existing in the spacecraft cabins. NASA-TT-F-273, 1964.

This paper discusses the findings in subjects isolated in chambers for periods varying from 10 to 120 days. Number of subjects, and number isolated at one time are not stated. Authors note that in ordinary conditions, the vital processes of an organism depend on the influence of the environment, whereas in the sealed cabin the environment is influenced by the organism in addition. Suggests that physiological changes observed may result from products of vital activity (e. g., CO). In 60 day tests initial changes were observed during a 10 to 15 day period corresponding to process of adaptation. Following this, a change occurs in regulatory mechanisms of blood circulation and respiration, e. g., systolic volume decreased from 50 to 40 ml, minute volume from 3.75 to 2.7 l. Response to graduated exercise was less than pre-test. Similarily O_2 consumption rises considerably and to larger extent than pre-test, while recovery of oxygen debt is appreciably delayed, i. e., efficiency at work is decreased. Author suggests this is due to a change in regulatory mechanisms and formation of a new "habitual stereotype" perhaps as a result of

65. (Cont) change of function in the CNS, as demonstrated by change of EEG. There are also definite indications of endocrine changes as exemplified by increase in excretion of 17-ketosteroids. A new habitual stereotype develops with normalizing of function such as sleep, motor reactions, light sensitivity of the eye, performance errors. At the same time, enhanced fatiguability persists; thus, adaptation is relative and "asthenization" symptoms develop towards end of test. Asthenization is represented by reduced working capacity, enhanced fatiguability, change in sleep function, weakening of immunal reactivity, reduction in functional potential of CVS, decrease in efficiency of work, and specific changes in dynamics of cortical processes. An "emergence reaction" develops on exit from the chamber and transition to ordinary life, characterized by deepening of asthenization, which, after 60 day test, may endure for up to two months. This is probably due to necessity of breakdown of the new habitual stereotype. By addition of other factors such as ionizing radiation, periodic rises in temperature, noise, and other factors, authors attempted to demonstrate the most significant environmental effects. They claim that the external medium and the chemical composition of the air appear to be the most essential factors affecting the human organism. They also noted psychic factors, e.g., higher excitability or irritation, and slight depression. Precise knowledge and purpose of tasks involved in the tests, feeling of responsibility and teamwork, execution of useful work all minimize deviations and improve morale. Preparedness for a given duration of tests is important, as demonstrated by the fact that observable changes during 10 day experiments were considerably more pronounced than during first 10 days of the two month experiment. Asthenization as a rule appears only toward the end of the test. Although the restriction of information has an unfavorable effect, standarization of life conditions contributes towards the formation of a new stereotype. Despite the stereotype, individual changes are still observable. Authors recommend that life conditions in the cabin should differ from ordinary conditions as little as possible, and that compatability of occupants must be carefully studied.

66. Levy, E. Z., Ruff, G. E., Thaler, V. H., Studies in human isolation. JAMA 169:236, 1959.

Authors distinguish between the microcosm and the macrocosm. Former is the environment apparent to the isolated subject, including physical structure of place of confinement, limitations imposed upon a subject, modality, quantity, and pattern of sensory input, duration of situation, and tasks. They note also concept of "perceptual space", namely, the space available in which the individual can perceive. Describe the results of 54 experiments in a dark and soundproof chamber (size unspecified) containing bed, chair, refrigerator, and chemical toilet. Subjects have remained up to 7 days. No unusual perceptual phenomena were found in the subjects although most reported a loss of urgency to think. Authors note that loss of cues from one modality of sensation may give rise to over emphasis on cues from other modalities. Change in pattern of sensation can be produced by reducing intensity and variability of stimulation or by addition of monotonous masking cues. Stimulus reduction may also disrupt psychologically significant relationships of subject with his environment. With respect to duration, the longer the isolation the more stressful it is; knowledge of planned duration makes isolation more tolerable. During first day of isolation, built-in clocks, e.g., desire to urinate, eat, sleep, and rate of beard growth, etc., are sufficient to give some idea of time. After a day or so this sense of time is lost and the result is very stressful. Most stressful situation occurs where subject has no control over duration. Existence of tasks may provide a structure to the environment.

Response to isolation varies with individuals. Schizoid subjects find it particularly stressful. Passive-dependent individuals seldom find short periods stressful although complaining of boredom and physical discomfort. Compulsive subjects expend great effort structuring situation around tangible bits of reality. Strongly motivated subjects consider it another task.

The macrocosm consists of reality factors, that is, the environmental circumstances inwhich the microcosm occurs. This includes the set of circumstances, e.g., being a prisoner, being lost, being an experimental subject.

67. Lowry, R. H., Konecci, E. B., An operating five-man 30 day life support subsystem. Presented at XIVth International Astronautical Congress, Oct. 1963.

Authors describe the requirements for the above system in terms of environment (sea level O_2/N_2), closed water system, food, and accommodations (total volume 2300 cubic feet). Continuous bacteriological and toxicological analysis were undertaken. After initiating a run, it was aborted after 5 days because of the development of extreme nausea in the subjects, with lethargy, weakness, and anorexia. Subjects in addition complained of eye itching and soreness of the gums with occasional bleeding. The cause was attributed to toxic build-up within a closed system.

68. McKenzie, R. E., Hartman, V. O., Welch, B. E., Observation in the SAM two-man space cabin simulator. III, System operator performance factors. Aerospace Med. 32:603, 1961.

Performance of subjects in this study was evaluated by measurement of their responses in a series of tasks undertaken on displays and controls within the cabin, mounted in panels in the work stations. Displays were scattered across three panels and were predominantly visual. Controls were located on two sides of the lower panel and were either of lever type or push button. A total of 14 tasks were employed. Methods were used for varying the signal rate per task. Tasks were conceptually assembled into four functional areas, namely, a navigation or orbital flight computer system, an airborne radar and doppler position system, a problem solving nuclear power control system, and a monitoring data telemetry system. Both 30 and 17 day missions were simulated as orbital missions. Work schedules were set up on a 22 hour day, allowing six to seven hours sleep. In the 30 day study, three major variables were explored, namely, effect of prolonged commitment to the task, duration of work, effect of differing signal rates. A scattering of differences was observed. No systematic effect for any variables was obtained. General finding was that performance was for the most part maintained at a stable level throughout the flight. In the 17 day flight (33, 000 ft.) a steadily increasing response time was observed. This was not obtained in the 30 day flight (18, 000 ft.) and perhaps reflected a reduced motivational state, perhaps aggravated by the fact that this was the second extended flight for two subjects. It may have also reflected the altered environments. A difference in response time

68. (Cont) was observed between night and day. This may have been partly due to diurnal variation, and partly due to different lengths of duty period. Task differences were more stable than in the 30 day flight.

69. Mallick, B. L., Ream, H. E., Crew performance and personal observations on Lunar mission simulation. IAS-63-18, 1963.

Authors observe that difficulties may result from small full cabin and a volume reduced sensory input environment. Suggest that findings in previous artificial studies are debatable because of non-realistic environment, lack of selection criteria, and performance of duties not applicable to space missions. Accordingly they tested a crew of 3 trained test pilots during analog simulation of the dynamic phases of the circumlunar flight. Especially difficult tasks, such as lunar landing, orbit rendezvous, and re-entry, were performed at the end of confined missions. Two missions of $3\frac{1}{2}$ days and one of 7 days were accomplished. Pilot performance was evaluated by comparison of pre-experiment or baseline runs with result obtained on the simulated missions. Flight control duties (dynamic phases) included launch and ascent, mid-course correction, orbit insertion, lunar landing, ascent, and rendezvous, re-entry and landing. The Martin-Marietta lunar mission simulator with the Langley one-man bug attached was used. Main vehicle has three abreast seating for Commander, Navigator, and Systems Engineer. Contained off-duty area, sleeping area, and sanitation area. Simulator was located in dark and soundproof room and crew flew from panel displays only, except for starfield projection utilized during bug rendezvous. 24 hour duty cycle on mission 1 consisted of 8 hours sleep and 16 hour wake period. Pilots found last few duty hours very tiring. Eye fatigue and boredom were noticeable. Because of eye fatigue and boredom, pilots found it difficult to focus on one spot and easy to stare. Pilots were unable to sleep entire 8 hours and became tired after two nights. Some contributory reasons were noises from communications, warning horns, airconditioning, movement of crew members, also variations in temperature, uncomfortable and restricted sleeping area. Average uninterupted sleep was four hours with remaining four hours dozing. A second duty cycle was adopted on mission two, splitting 8 hour sleep periods in 2 four hour periods and a 9 hour wake period in between. This provided a 26 hour day but was found very agreeable to pilots. Cycle 2

69. (Cont). was utilized in the 7 day mission satisfactorily. Music was found valuable in combating boredom.

A physical preconditioning program was started two months prior to first mission, during which pilots lost average of 15 pounds per man. On board, pilots used bungee-type device in four 15 minute exercise periods on first mission. More frequent exercise was undertaken on later mission. Physical condition evaluation before and after each mission showed no apparent degradation of condition resulting from reduced activity in the confined area. Evaluation included Harvard step test. No complaints of discomfort, e. g., back pain or leg weakness encountered on other simulations. Crew members showed no noticeable effect.

Pilot alertness, indicated by ability to cope with emergency, showed no deterioration with confinement.

General conclusions were that no difficulties occurred with test pilot personnel for confinement periods up to 7 days. A 26 hour duty cycle with 2 four hour sleep periods was found suitable for a 3 man crew and no decrement in performance resulted. (See Grodsky and Bryant, 1963).

70. Miller, P. B., Hartman, B. O., Johnson, R. L., Lamb, L. E. Effects of two weeks bed rest on circulatory functions. Aerospace Med. 35:921, 1964 (Author's Summary)

The effects of 2 weeks of bed rest on circulatory functions were studied in 72 healthy subjects, utilizing two different intervals of 2 weeks' bed rest. The value of various procedures in maintaining normal cardiovascular reflex regulatory mechanism during bed rest was evaluated. A 15-fold increase in syncopal reactions and a significant increase in orthostatic heart rate occurred after 2 weeks of bed rest. Physical activity and tilt table training for 4 weeks between the two bed rest periods resulted in a decrease of the resting heart rate and an improvement in orthostatic tolerance. An improvement in orthostatic tolerance after bed rest was noted with the various prophylactic procedures utilized in this study. A program consisting of exercise and tilt table training before bed rest and intermittent venous occlusion in the extremities during bed rest in a 10-degree head-up bed resulted in almost complete preservation of normal orthostatic tolerance. Various in-bed procedures tended to prevent hematological changes previously noted with simple bed rest. An antigravity suit proved very effective in preventing postural syncope after bed rest.

71. Miller, P. B., Johnson, R. L., Lamb, L. E., Effects of absolute bed rest on circulatory functions. Aerospace Med. 12:1194, 1964 (Authors' Summary).

Various effects of 4 weeks of absolute bed rest on the circulatory system were studied in 12 healthy male volunteers. Postural tolerance varied from day to day before and after bed rest. Repeated tilt table testing allowed a more accurate appraisal of change in postural tolerance caused by bed rest. Postural syncope on the tilt table was more frequent after bed rest. Forty-two percent of the subjects, however, did not faint during repeated testing after bed rest. A comparison of the highest orthostatic heart rates recorded during each tilt table test without an antigravity suit before and after bed rest showed a distinctly higher range of orthostatic heart rates after bed rest in each subject studied. When an antigravity suit was worn during tilt table testing after bed rest, postural syncope occurred on one occasion only. The relation of these studies to proposed flights in the Manned Orbital Laboratory is discussed.

72. Mitchell, M. B., Time disorientation and estimation in isolation. WADD-ASD-TDR-62-277, 1962.

Thirty-four Air Force subjects, including 10 test pilots, were isolated individually in the WADD isolation chamber, a converted anechoic chamber, 13 x 7 x 6, containing a refrigerator, bed, and chair. They estimated one hour duration in a lighted environment, and one hour without lights by depressing a button for one second every 6 minutes except at the 30 minute interval when they depressed it for 5 seconds, and at 60 minutes when they depressed it for 10 seconds. In addition 10 subjects continued to push in the same manner for four hours in light with a clock. Eight subjects continued in dark isolation without a clock for 48 hours and indicated 4 and 8 o'clock by depressing a button for 1 second, noon by depressing it for 5 seconds and midnight by depressing it for 10 seconds. One second was overestimated, 5 seconds was judged accurately, and 10 seconds underestimated, while 6, 30, 60, and 120 minutes were significantly underestimated. Twelve subjects, including 3 test pilots, became confused during the 2 hour estimations and gave the wrong number or rhythm of pushes. Five of 10 subjects also became confused when given a clock. Four hour estimations tended to become steadily shorter over 48 hours in dark isolation. Two subjects defected.

73. Myers, T. I., Murphy, D. B., Smith, S., Windle, C. Experimental assessment of a limited sensory and social environment. HUMRRO-62-2, 1962.

Authors describe the responses of 8 volunteer subjects, each exposed in a light-proof and soundproof cubicle, approximately 7 x 9 feet, specially constructed for the purpose. Exposure was continuous up to a maximum 96 hours. Limited floor space of cubicle was almost covered by bed, toilet, and refrigerator. Subject was maintained on a liquid diet. Subjects were medically screened and continuously monitored. Subjects were male enlisted Army personnel, randomly selected. From volunteer group, both cubicle and control group were selected. Non-volunteers were also retained as controls. Pre-isolation, isolation, and post-isolation tests were conducted. During the stay in the cubicle subjects talked very little, spent a substantial time in bed, fidgeting, squirming, and restless. They thought and dreamed about the past, with frequent frightening and strange thoughts. Some became fearful; many could not distinguish wakefulness from sleep. One-third requested release prior to four-day period, chiefly because of restlessness, tenseness, nervousness, persistence of unpleasant thoughts, inability to sleep and intense boredom. A post-isolation questionnaire showed the nature of hallucinations and thoughts. Another questionnaire, involving selection of certain descriptive words and phrases, provided an indication of subjective stress. Stress was found significantly greater than that reported by baseline, i.e., the normal stress for Army life prior to arrival. Similar analysis for controls showed lack of stress in the control period. Estimation of intellectual functioning by questionnaire showed that the cubicle subjects reported considerable inefficiencies in thought processes during their time in the cubicle. Intellectual tests given pre-isolation and during isolation indicated that cubicle subjects were significantly poorer on inductive reasoning and successive subtraction tests than were control subjects. Auditory vigilance, namely, detection of a 500 cps tone presented for 1/10 of a second against a background of silence at 50 db, showed that the average response latencies of the cubicle group were faster than those of the two control groups, one in the dark and one in light. The lighted room control group was significantly superior to the dark control group. The cubicle group was not significantly better than the lighted room control group. A semi-objective measure of visual sensations was attempted. Sensations were classified in terms of complexity during a 30 minute period in which subjects reported all visual sensations. The first measure

73. (Cont). was obtained after 72 hours of confinement and was accompanied by a control response. The second measure was obtained following termination of experimental confinement and referred to the entire time subjects had spent in the experiment as cubicle subjects or controls. Mean scores for the first measure indicated that complexity of sensations reported by the two groups was essentially similar. Mean scores for the second measure indicated that, during the course of the experiment, cubicle subjects reported sensations of greater complexity than control subjects. Thus, the difference between visual experiences lies not so much in complexity of sensations during a limited reporting time but in the opportunity provided for cubicle subjects to sample a wide variety of sensations, which may have cumulative effects.

General conclusions were that dark quiet isolation is a stressful experience. Evidence of intellectual inefficiency was obtained. Cubicle experience was characterized by vivid and complex visual sensations, although complexity of these events at one point in time is not distinguishable from that of control. There were indications that monitoring an auditory signal was enhanced by several days of isolation.

74. Morgan, T. E., Ulvedal, F., Welch, B. E., Observations in the SAM two-man space cabin simulator. II. Biomedical aspects. Aerospace Med. 32:591, 1961.

Prior to confinement the subjects concerned in the experiments underwent psychological and physical examination, measurement of work capacity, orthostatic tolerance, pulmonary function studies, dental, audiologic, x-ray, and ophthalmologic examination. Complete urinalysis and hematology studies were made along with cardiologic and bacteriologic surveys. Metabolic rate, alveolar gas, body water, blood and plasma volumes, were also measured. Most of the preflight clinical tests were continued through the experiment. Hematology, bacteriology, clinical chemistry, urinalysis, audiology, dental and ophthalmologic examination showed no significant changes during and after the experiment. There was a significant decrease in resting diastolic blood pressure in both subjects at 18,000 feet and in one at 33,500 feet. Physical performance by treadmill showed a reduction after the flight but decrease was not so marked as that from water immersion, although larger than that produced by 4 weeks of bed rest alone. Orthostatic tolerance, by tilt table, was not greatly affected. Minor changes observed were not comparable with those found after water immersion. Unexpected weight loss occurred, with decreases in total body water, total blood volume and plasma volume. Loss of total

74. (Cont). body water was larger than corresponding loss of body weight. This suggests to the authors a shift in body composition with greater proportion of fat at conclusion of experiment. Gradual weight loss seems to occur about same rate regardless of altitude. Rapid recovery occurs after 17 days, as opposed to longer recovery after 30 days. These findings suggest that dehydration is responsible for weight loss in 17 days study, while after 30 days change in body cellular composition occurs. Cause is not clear since simple dehydration is unlikely in the face of an adequate water supply and relative humidity. Diuresis produced by altitude has been suggested but has not been confirmed by a comparable increase in hematocrit or plasma osmolarity. Pulmonary functions and other studies to evaluate the use of an oxygen atmosphere were carried out. Some changes in pulmonary functions were observed along with symptoms of discomfort. No atelectasis was observed by x-ray examination.

75. NASA-Results of First United States Orbital Space Flight. NASA Doc. 398, 1962 (a).

76. NASA- Results of Second United States Orbital Space Flight. NASA SP-6, 1962 (b)

77. NASA-Mercury Project Summary including Results of Fourth Manned Orbital Flight. NASA-SP-45, 1963.

78. NASA - Proceedings of Gemini Mid-Program Conference, (Parts 1 and 2) Manned Space Center, Houston, Texas, 1966.

79. Ormiston, D. W., A methodological study of confinement. WADD-TR-61-258, 1961.

Author defines sensory deprivation as reduction or curtailment of all manipulatable sources of stimulation; isolation, as a separation from society; confinement as any situation which restricts movement of the individual. Sensory deprivation carries some degree of the other two conditions. Confinement includes some limitation of sensory inputs, but does not require isolation. Isolation can be effected in a relatively pure form, i. e., without confinement or sensory deprivation.

Aim of this study was to provide information for the methodology of confinement through development of better criteria, further investigation of relationships between personality and reactions to confinement. Evaluation was undertaken by a battery of 5 personality tests, and 2 psychomotor performance tasks, namely, a monitoring task involving a response to a red warning indicator, and a dual compensatory tracking task at the end of the first hour and thereafter every 2 hours. Continuous estimation of successive ten minute time intervals

79. (Cont). was evaluated. Somatic complaints were recorded by the subject. Volunteer male undergraduates were paid to serve as subjects, 18 in group 1, 17 in group 2, and 19 unconfined controls. Each subject was confined in a 5 x 8 x $6\frac{1}{2}$ feet windowless cubicle. He carried lunch, and water was provided. Furnishings comprised a small table for performance apparatus and an aircraft seat. Cubicle was not soundproof but noise of fans masked external noises. A urine receptacle was provided. Cubicle was lit by a standard 75 watt bulb. Personality tests were presented to the groups during a period of 1 to 3 months before confinement and again after confinement. Visual illusions, namely, the phi phenomenon, the autokinetic phenomenon, the spiral after effect, and the Necker cube were presented to the groups before and after confinement. Duration of confinement was 8 hours. Significant results for the spiral after effect, namely, increase in duration for confined subjects, were in agreement with those of other workers. Onset of the autokinetic effect did not yield significant changes. Changes in fluctuation of cube and the phi phenomenon thresholds were of doubtful significance and in conflict with other data. Relationships between somatic complaints, namely, drowsiness, muscular fatigue, headache, stomach upset, numbness, and cubicle temperature, with performance were obscure, as were relationships between personality measures and performance. No significant changes occurred in tracking tasks between groups. No significant changes were observed in the constant monitoring task, perhaps because the additional tasks relieved boredom and restored performance on the monitoring task. No difference occurred related to whether subjects began confinement in morning or afternoon. Author discusses the results of his study in relation to those of other sensory deprivation or confinement studies.

80. Ormiston, D. W., Finkelstein, B., The effects of confinement on intellectual and perceptual functioning. WADD-ASD-TR-61-577, 1961.

This study concerns the variation of performance in 20 selected Air Force Officers confined for 48 hours individually in an escape capsule with maximum diameters 5' x 2' x 2'9''. Capsule contained task requirements, intercom, windows in canopy, water and fluids ad lib, relief tube for urination. Defecation was unnecessary. Subjects worked periodically on arithmetic, memory for digits, confusing sentences, nonsense syllables, verbal analogies, same-opposite word meanings, logical reasoning, imbedded figures, form discrimination, simulated aerial reconnaissance, compensatory tracking, and warning light monitoring. Confined subjects received $8\frac{1}{2}$ hours sleep each night. Tasks were devised to provide for testing of

80. (Cont). intellectual, perceptual and tracking capacities as well as test of special diets. With exception of a relationship between diet and scoring in the aerial reconnaissance test, there were no significant differences between performance trends of the treatment groups. Exception is believed to be due to chance. Test diet subjects, confined or not, with daily consumption of 1800 calories showed mean weight loss of 2.15 pounds over 48 hours. Subjects on low residue diet, 2900 calories, experienced a mean gain of 0.4 pounds. General conclusions were that individual close confinement for 48 hours apparently had no appreciable effect on intellectual functioning, as measured. Perceptual speed, accuracy, and form discrimination, appear to be regularly maintained under confinement conditions. Warning light monitoring does not suffer. Confinement brings increase in irritability in subjects with perhaps expression of undesirable behavioral tendencies. Bizarre behavior and performance decrement do not occur in confined subjects as compared with sensory deprived subjects. One episode of fear was noted. Other conclusions were noted related to diet acceptability.

81. Peters, J. M., Benjamin, F. B., Helvey, W. M., Albright, G. A., Study of sensory deprivation, pain and personality relationships for space travel. NASA-TN-D-2113, 1963.

This study was devised to explore the hypothesis that sensitivity to pain is negatively correlated to sensory deprivation sensitivity, and positively correlated to certain personality variables. Two groups participated, one of 33 subjects from a seminary, the other of 29 Air Force non-coms. Various pain tests and psychological tests were given to members of each group then each subject was confined on a contour couch in a full scale model of a multi-man space capsule. No movement was permitted and minimum communication took place. Records of EEG, EKG, and respiration rate were made. Written records were kept of water and food intake, urine and fecal output. Each subject wore ear defender head sets and translucent goggles. Low level white noise was fed into head set. Subjects wore heavy leather gloves and heavy wool socks. Minimal bland diet was provided. Subjects were instructed to remain in isolation as long as possible. Unknown to the subjects a maximum time of 40 hours was preselected. The numbers remaining for different periods are not stated but three groups were selected, a high group with a mean of 39.9 hours, an intermediate group with a mean of 36.1 hours, and a low group of 26.3 hours. Results showed that subjects could be categorized into groups most, average, and least able to endure pain. No consistency in results of psychological testing among the groups was observed. The hypothesis was not proven; in fact the opposite was shown, i.e., a direct rather than an inverse relationship between variables. In addition subjects most able to endure pain and reduced

81. (Cont). sensory input conditions suffered less anxiety without any headaches, or nausea, and remained in good functional condition for a longer period of time.

82. Rathert, G. A. Jr., McFadden, N. M., Weick, R. F., Minimum crew space habitability for the lunar mission. NASA-TN-D-2065. 1964.

This report describes a 7 day habitability study with two men in a space cabin simulator. Only the stresses produced by restricted work space are considered. No attempts were made to provide a closed ecological system or simulate unusual environmental conditions or atmospheres. Factors of sensory deprivation and isolation were present to some degree but not emphasized. Capsule was a conical shell with smooth inner surface of plywood and outer covering of soundproofing material. Cone had angle of 60° and a removable, nearly spherical, base. Cone was supported such that center line was horizontal. Internal furnishing included 2 chairs, instrument panel, food and supply cabinet, wash water system, pass-out box, and removable toilet seat. Chairs were hinged so that one could form a cot. Total internal volume was 149.5 cubic feet with irregular shape. Available volume was 123 cubic feet, or 61.5 cubic feet per man. Subsystems consisted of provisions for food, water, air circulation, waste removal. Subjects were placed on diet (Air Force in-flight ration #10) four days before confinement and three days after. Waste products were removed through pass-out box. Cabin atmosphere was air conditioned for temperature control by subject. Humidity was about 31%. Subjects were permitted normal personal hygiene equipment. Subjects remained for 7 days on four-hour schedules. Tasks were completed during the 24 hour day on a shift basis. These were in three categories: engineering tasks, including various monitoring control problems; psychological tasks, self-monitoring, and independent research; medical tasks, monitoring and research. Tracking task showed no significant decrement or trend during the period. In a photographic and mathematical computation navigation task, the subjects' ability to make required measurements remained satisfactory, although errors occurred in arithmetic, probably because of design of task. A mission status monitoring task showed that subjects' alertness apparently did not deteriorate during the period. A vigilance task demonstrated that performance remained either constant or improved. A rate estimation task showed a general decrement in accuracy of velocity perception. A pattern discrimination task showed decrements which may well be attributable to disinterest rather than to a real decrease in discriminative ability. A letter cancellation task showed a consistent day to day rise in speed of task performance. Decrements in performance occurred related

82. (Cont). to task complexity. Physiological studies are also detailed. Physiological deterioration was similar to that to be expected from a week's confinement to bed, but less extensive. A potentially serious finding was the excretion of calcium in excess of intake in one subject. Subjective examination of subjects indicated that the situation was tolerable and could be endured for longer periods.

83. Ruff, G. E., Levy, E. Z., Thaler, V. H., Studies of isolation and confinement. Aerospace Med. 30:599, 1959.

Authors detail two types of experiments. In the first confinement was studied under simulated operational conditions with five men in a compartment 17 x 7 x 6 feet for five days. Various group and individual psychological and biomedical measures were made. The results from three groups showed that crew members began with a positive attitude to each other and tended to maintain it. Each group had a characteristic personality. Projective tests showed a trend towards regressive behavior. Transient ego impairment was occasionally noted. Individually, each subject used characteristic methods to handle conflicts. Physiologic and biochemical measures suggested that the experience was only moderately stressful. Blood and urine studies remained within normal limits, except for some signs of dehydration in some members during the immediate post-run period.

A second type of experiment investigated how different individuals react to unusual situations. Each study involved placing subjects alone in a soundproof room containing bed, refrigerator and toilet. Pre- and post-run psychologic tests were used similar to those of the first group. Physical and biomedical tests were included. Nine experiments were carried out involving more than 100 separate runs, ranging from 3 hours to 7 days. Experimental conditions varied. At least 8 groups of variables were found to influence behavior during isolation, namely, (1) circumstances surrounding the isolation, (2) subjective personal factors, (3) type of sensory input, (4) nature of confinement, (5) extent of communication, (6) aloneness, (7) duration of isolation, knowledge of duration, degree of control over duration, and presence or absence of time measures, (8) activities undertaken by subject. A characteristic behavior pattern was found, involving an initial brief panic followed by structuring of the experience according to needs of person. If the experiment is long enough anxiety reappears and thoughts become disorganized. As unconscious material tends to come out defenses become more primitive, and subjects may request to quit. Studies have implications both for design of vehicles and selection of members, and indicate a necessity for meaningful information. Capacity

83. (Cont). to withstand isolation also depends on integrity of subject's personality. Stress isolation increases with time. Knowledge of very prolonged isolation is lacking. Even slight reductions in information content and variability may eventually become stressful. Effects may be mitigated by emphasis on whatever channels are available for gratification of drives.

84. Scott, T. H., Bexton, W. H., Heron, W., Doane, B. K. Cognitive effects of perceptual isolation. Canad. J. Psychol. 13:200, 1959.

Twenty-nine male college students were tested before, during, and after a period of isolation (usually 3 - 4 days). They were given verbal intelligence test items, performance tasks, and attitude scales, and were subjected to recorded "propaganda material." The experimental Ss performed worse than the control group both during and after the isolation period on some tests, and were more susceptible to propaganda, though both groups showed a significant change in attitude. After isolation Ss reported inability to concentrate, and there was some evidence of impaired judgment.

85. Sells, S. B., Berry, C. A., Human requirements for space travel. Yale University Quarterly Review. 108, 1958.

Authors state that isolation involves different conditions having a common denominator of separating the individual from significant parts of his environment. Confinement refers to restraint or restriction of freedom of movement or action, by command, fear, physical enclosure, or encapsulation. Confinement produced by dimensions of cabin, harnesses, garments, and personal equipment may have harmful effects on the individual and the group efficiency. Aloneness and separation are factors, the adverse response to which could be screened out by pre-selection and improved by conditioning, by prior levels of exposure, effective use of communication, discriminate matching of personalities in crews, and effective application of group dynamics and crew coordination. Cumulative effects may be observed in combined stresses.

86. Selye, H., The physiology and pathology of exposure to stress. ACTA Inc., Montreal, 1950.

87. Solomon, P., Leiderman, P. H., Mendelson, J., Wexler, D., Sensory deprivation: A review. Amer. J. of Psychiatry, 114:357, 1957.

This paper is a comprehensive review of literature on sensory deprivation.

Authors conclude that while there are many separate factors operating in the various situations that produce sensory reduction, it is clear the the stability of man's mental state is dependent upon adequate perceptual contact with the outside world. Observations have shown the following common features in cases of sensory deprivation; the intense desire for extrinsic sensory stimuli, and bodily motion, increased suggestibility, impairment of organized thinking, oppression and depression, and, in extreme cases, hallucinations, delusions, and confusion.

88. Steinkamp, P. R., Hawkins, W. R., Hauty, G. T., Burwell, R. R., Ward, J. E., Human experimentation in the space cabin simulator. AF-SAM-59-101, 1959.

This paper initially describes the development of the SAM one-man space cabin simulator. The basic shell measured 96 cubic feet. Exposure factors included a simulated altitude of 18,000 feet and extreme degree of physical confinement, including immobility, isolation and sensory deprivation, a work-rest schedule comparable to space activity, variation of nutritional support, noise, limited facilities for personal hygiene. Cabin contained a seat-couch with a feces receptacle, and separate urine receptacle, with limited storage facilities, pre-packaged food supply, a work panel, and internal environmental control system. Paper describes 5 studies of 7 days exposure. All subjects were physically and psychiatrically examined and psychologically evaluated prior to the experiment. They each received 2 day pre-flight indoctrination. Throughout the flight, subjects were committed to a 4:4 work-rest ratio. ECG and respiration were continuously monitored, and closed circuit television was available. Cabin pressure was maintained at about 380 mm Hg for 7 days with an oxygen tension of about 150 mm. Temperature and humidity were relatively constant. Examination of heart and respiratory data reveals no indication that a physiologic adaptation occurred in the 5 subjects as a result of being subjected to a 4:4 schedule. Scheduling, however, affected performance ability on a task panel provided within the cabin, in that the first subject developed progressive fatigue and deterioration. Subsequent flights were conducted with pilots of appropriate background and experience. These subjects accepted the task as being merely another job and consequently adjusted to the 4:4 ratio at work and rest. In general, if behavior was

88. (Cont). purposeful and directed towards objectives relative to the situation, adjustment was possible. Much of the activity of the first subject was restless and aimless in nature. Adjustment was assisted by arranging activities in rational sequence and in developing a disciplined time schedule. With the latter subjects, although the environment was impoverished, no aberrant behavior was observed or reported. This was again probably because of work and rest scheduling along with sensory stimuli provided by the cabin environment. Post-flight circulatory studies on the tilt table with breath holding, hyperventilation and carotid pressure showed that heart rate accelerated much more rapidly than on the original examination, and that in each case recovery was much slower. The physical condition resembled the pattern found among convalescent patients during prolonged bed rest. Findings returned to normal within 24 hours.

89. Strope, W. E., Etter, H. F., Buldbeck, R. A., Keiskell, R. H., Sheard, J. H., Preliminary report on the shelter occupancy test of 3-17 December 1959. USNRDL-TR-418, 1960.

This paper describes the results of a test to determine the feasibility of a bomb and fallout shelter, 25 x 48 feet in area with an arched type roof. After a 48 hour pre-test with 17 people, the shelter was occupied by 100 male volunteers, including 92 inmates from a rehabilitation center, 5 deputy sheriffs, and 3 USNRDL investigators for a period of 14 days. Volunteers were medically screened before entering. During occupancy all aspects of shelter environment were monitored as well as actions and responses of occupants. Daily medical conditions, environmental conditions, and subjective interpretation of psychological conditions were recorded. Continuous external observations were made by way of closed circuit TV and audio systems, and by monitoring temperature, humidity, and carbon monoxide. A physician was available for daily sick call. All volunteers were advised that they could quit at any time. None quit voluntarily; two were removed for medical reasons. Bunks could be erected for sleeping purposes; tables and benches were available for recreation and eating purposes. Sanitary facilities were minimal but adequate. A shelter organization was formed, partly mandatory and partly permissive. Inmates formed themselves into groups with elected leaders reporting to shelter management personnel. Various difficulties occurred with inadequate or poor quality equipment. Group cleanliness was a problem. Use of limited space seemed satisfactory. At beginning of test, impression was one of great crowding. This diminished as traffic patterns developed and organization occurred. Space was inadequate for storage, both public and personal. A major adverse aspect was lack of privacy.

89. (Cont). Questionnaires indicated that 96 inmates would have volunteered again but that hardships were present and conditions could have been improved. 96 indicated that they could have stayed another week, 91 for 2 weeks, and 88 for 3 weeks. Major discomforts were restricted water, lack of space, seating discomfort, noise, diet, boredom, sleep conditions, environmental conditions, and others. No bathing or shaving was possible. Only waterless methods of face and hands washing were permissible. There was no limit on drinking water. Lack of space was chiefly observed in storage and privacy. Medical problems were minimal, a fact contributed to by pre-test screening. Some loss of weight occurred, averaging 2 pounds on one diet and 4 pounds on another diet. Little or no infective conditions developed. A strong motivation was maintained among the inmates, all strongly desiring to finish the test. About the 5th to 7th day, many mentioned that they were starting to feel tired and listless and were having difficulty in remembering details.

90. Strope, W. E., Schultze, D. P., Pond, J. I. Preliminary report on the shelter occupancy test of 25-29 July, 1960. USNRDL-TR-502, 1961.

This is a report on the second test carried out on the USNRDL shelter after some modifications based on recommendations from the first test. 100 volunteers from a rehabilitation center maintained occupancy for 5 days. The 5 day occupancy was based on evidence from previous experiments that the objectives could be met by a shorter staying time. During this 5 day period, all aspects of the shelter environment were monitored, as well as the action and responses of the occupants. Daily medical conditions, environmental conditions, and subjective interpretation of psychological conditions were recorded. Most of the comments were devoted to the discussion of the facilities. 99% of the occupants indicated they could have stayed for another week, 92% for 2 weeks, 80% for 3 weeks; 15% indicated that occupancy was a difficult hardship. Major discomforts in order of rank were noise, ventilation, lack of space, sleep conditions, diet, restricted water for purposes other than drinking. Medical complaints were infrequent and minor. Headaches were most frequent, followed by afebrile upper respiratory infections and skin rashes. The latter may have been due to a waterless hand cleaner. A general lowering of standards of behavior was observed in the group and a lack of interest upon the part of most occupants in matters of civil defense, which was attributed to a deliberate passive role adopted by the shelter commander.

91. Tiller, P. R., Figur, A. M., Environmental requirements of sealed cabins for space and orbital flights. A second study, Part IV. Concentrations of epinephrine and norepinephrine in urine during confinement in a simulated space chamber. NAMC-ACEL-416, 1959.

This paper discusses the excretion of epinephrine and norepinephrine in the NAMC simulator described elsewhere. (Hendley and Mancinelli, 1958). 24 hour urine samples were analyzed immediately before, during and two weeks after the experiment, using a fluorometric technique. Epinephrine excretion showed in general an increase during the first few days over the pre-run determinations, and a fall off on days 7 and 8 towards the end of the run. Mean excretion of 6 subjects for 8 days of confinement was approximately twice excretion of post-run determination. Volume of excretion of norepinephrine was not constant, either between subjects or within subjects, with the exception of day 5, when an increase was observed generally. Excretion of norepinephrine-like substances is associated with a tense, anxious, but passive display of behavior. The increase of excretion of norepinephrine on day 5 was attributed to an episode which caused the subjects to be hostile towards the experimenters. The increase in excretion of epinephrine was attributed to anxiety and tension arising from confinement per se. Subjects were aware that the study was being conducted at sea level and that there was little or no danger.

92. Volynkin, Yu. M., Yazdoviskiy, V. I., The first manned space flights. Med. Biol. Inst. Moscow, 1962. FTD-TT-62-1619, 1962.

93. Walters, R. H., Henning, G. B., Isolation, confinement, and related stress situations. <u>Aerospace Med.</u> <u>32</u>:431, 1961.

In this paper the authors draw attention to difficulties of trying to develop theories to integrate the diverse problems and responses to isolation, sensory deprivation, and confinement. The effects of sensory deprivation and social isolation have been inextricably confounded. Some situations, <u>e. g.</u>, solitary travel and space flight, provide a wealth of sensory input but little opportunity for social contact. Some of the effects of sensory deprivation are probably more closely related to fear of abandonment. Many of the social isolation situations involve small groups rather than single individuals. At the same time responses of people habituated to such environments are unlikely to parallel those of people suddenly deprived of accustomed social and cultural experiences.

94. Welch, B. E., Morgan, T. E., Ulvedal, F., Observations in the SAM two-man space cabin simulator. I. Aerospace Med. 32:583, 1961.

This paper describes two experiments, one conducted at 18,000 feet with 40% oxygen, 60% nitrogen, for 30 days 8 hours, and 21 minutes; the other conducted at 33,500 feet with 100% oxygen for 17 days, 21 hours, 27 minutes. The cabin was an elliptically shaped steel cylinder, 12 feet long, 8 feet high, 5 feet wide, and with a total bound volume of 380 cubic feet. It was designed for control of total pressure, oxygen partial pressure, carbon dioxide partial pressure, temperature, relative humidity. It was divided into two areas, a rest area and a work area. The rest area was used for water purification, oxygen, food and water storage, work table and sleeping. The work area was utilized as a control center of the vehicle, and included a control panel containing psychomotor performance equipment, environmental systems control, transfer switches, indicator lights and analyzer calibration equipment. Two trained pilots were used as subjects. Body weight was determined before and after both flights. Energy intake was determined by providing weighed food packages of known caloric content. Records were maintained of liquids used, and volume of urine produced. During 30 day flight, the men lost 3.64 and 2.85 kilograms, while during 17 day flight they lost 2.05 and 1.93 kilograms. Exact composition of weight loss is not known, but is believed to be primarily water loss combined with some re-arrangement in body composition. The measured energy intake values of 1406 and 1890 Kcal for subject A and 1667 and 1940 Kcal for subject B are below previous estimates for energy requirements in similar situations. Average energy for both men for both flights was 1726 Kcal/man/day. Average daily water usage for both men for both flights was 1931 ml., including water for personal hygiene but not from food or water oxidation. Oxygen requirements were 1.13 pounds/man/day or 360 liters.

95. Welch, A. E., Morgan, T. E., Ulvedal, F., Sealed cabin experimentation. Am. Rocket Soc. J. 31:541, 1961.

This paper deals with the logistics of the SAM two-man sealed cabin experiments. These experiments lasted 14, 17, 30, and 30 days at altitude of 18,000, 33,500, 18,000, and 18,000 feet respectively. Food was supplied in a pre-cooked dehydrated form. Approximately 1 lb. of food was required per man per day to supply from 1160 to 1915 Kcal. Water requirements were found to be about 2 liters per man per day. Urine produced was approximately 1 liter per man per day. Size of cabin is 12 x 8 x 5 feet with a bound volume of 380 cubic feet.

96. Weybrew, B. B., Psychological effects of long periods of submergence 1. USN Med. Res. Lab. Report 281, 1957. (Author's Summary).

Thirty enlisted men from the crew of the Nautilus were measured daily during an 11 day, completely submerged period to determine when, or if, any debilitating effects resulted from this period of submergence. Critical flicker frequency thresholds, hand tremor scores, heart and respiratory periods, and daily self-ratings on 28 fatigue-like variables were included in the measurement battery.

The data from each test, plotted by day submerged, suggest that optimal adaptation to the submerged conditions occurred during the first six days. From the 6th to 8th days, muscular tension increased and the proportion of individuals reporting insomnia, headaches, and lowered motivation also increased, thus suggesting less effective adaptation during this period. The data for the last two days indicated more effective adaptation; however, these results were considered spurious due to the "end spurt" previously observed in men living in confined environments for prolonged periods.

97. Weybrew, B. B., The impact of isolation on personnel. USN Med. Res. Lab. Report 358, 1961.

98. Weybrew, B. B., Psychological Problems of Prolonged Marine Submergence. in Unusual Environments and Human Behavior, (Ed.,) Burns, Chambers, and Handler. The Free Press of Glencoe Collier-MacMillian, London, 1963.

Submarines such as Nautilus and Triton with a 400 feet steel hull have remained submerged for 60 to 63 days while transiting beneath Arctic Icecap and circumnavigating the World. Duration of submergence is limited only by food, oxygen and other vital essentials. Although size of submarine has increased by one-third and size of crew by the same, the space per man has decreased because of additional instrumentation. Facilities for 100 to 170 men are required. Majority of crew adapt to confinement; 20% of 331 men indicated dislike of confinement; general living conditions also being disliked. Physiologically, atmospheric problems have been studied. Headaches of varying degrees of severity have been reported by 15 to 40% of the crew on any one day during protracted submergence. Cause has been attributed to atmospheric conditions, sympatheticotonia, or vagotonia as a consequence of increased level of carbon dioxide. Author quoted study on 22 men confined for 60 days in submarine. Based on changes in pulse rate, blood pressure, blood cell counts, and presence of urinary excretary products (urinary 17-ketosteroid production), it was reported that some adaptation had occurred.

98. (Cont) Concluded that no physiological effects of debilitating nature had occurred. In same study, psychomotor effeciency was noted to have declined. No evidence of strange hallucinatory behavior is reported. This indicates that latter is probably associated with isolation, not confinement. Author notes the considerable importance of motivation amongst submarine crew as a factor in maintaining morale in confinement. He also notes reports from crew of Nautilus requesting modification of berthing and leisure time facilities so as to provide more opportunities for privacy. Reduced alertness is a common finding, along with some decline in performance. Significant drops in eosinophil counts have been reported during 8 weeks of simulated submergence. During a 12 day sealed cruise of the Nautilus there was a trend towards increase in subjective tension, difficulty in sleeping, and increased interpersonal irritability, along with increase in frequency and severity of headaches. Author includes much other information on psychomotor performance, behavior, assessment, and selection.

99. Wheaton, J. L., Fact and fancy in sensory deprivation studies. USAF SAM Aeromedical Reviews 5-59, 1959.

This paper is chiefly concerned with isolation and sensory deprivation. With other discussions, it includes a review of anecdotal and clinical literature on isolation, and experiments on sensory deprivation. Author states that essential nature of isolation is the separation of an individual from objects in his environment. It can occur in a number of ways and may vary in degree. Objects from which individual is isolated may vary in significance for him. Sensory deprivation consists of a reduction of the totality of stimulation in the environment, thus reducing the non-specific arousal stimulation. This arousal is coordinated by a regulating system, apparently a function of the reticular formation of the midbrain, which coordinates some of the external stimuli so that the individual retains the level of awareness commensurate with the demands of the environment. Author points out three mechanisms of isolating an individual, namely, confinement to a limited space, separation from particular stimuli to which individual has attachment or dependency needs, and separation from environment of areas of stimulation. Confinement may often involve one or both of the other. Essential principles of accomplishment of confinement are: restraint of movement as by seat belt or shoulder harness, barriers such as locked door, wall, command, or threat, encapsulation, as in a full pressure suit with helmet, or cramped living space such as that of sealed cabin, and time restrictions such as curfew.

100. White, S. C., Reed, J. H., Habitability in space stations. AIAA-63-138, 1963.

Habitability is considered to be the resultant of the interplay of all the factors related to man, his machine, his environment, and the mission to be accomplished. Design and development of a space vehicle should avoid depending upon a special selection and unusual training to meet the basic provisions needed to support man in the space environment. Vehicle provisions should stand on their own merit. Habitability is dependent upon the nature and duration of mission, crew size. The authorsdiscuss, in a very general manner, work cycles, sleep, relaxation, and diet.

101. Zubek, J. P., Counteracting effects of physical exercises performed during prolonged perceptual deprivation. Science, 142:504, 1963.

Author describes a combined confinement and perceptual isolation study in which 27 male students were placed individually in a dome shaped chamber, 7 x 9 x 7½ feet for 7 days. Washroom facilities, food chamber, and air conditioning unit were provided. The only furniture was a mattress. Eighteen subjects endured for a full week. Behavior was monitored by intercom and closed circuit TV. Subject wore translucent goggles, eliminating all pattern vision, and earmuffs through which white noise somewhat above threshold of hearing was constantly presented. No gloves were worn. Singing, humming, or other vocal activity was not permitted. No restrictions were placed on motor activity. In addition, 6 five minute exercise periods were introduced at irregular intervals each day. Results of EEG, observed behavior, and performance on 15 behavioral measures, were compared with similar tests carried out under identical conditions with another group without exercise. With exercise, only 3 behavioral measures were impaired, in contrast to 10 out of 15 without exercise. Fewer hallucinatory phenomena or less disturbance of EEG were observed.

102. Zubek, J. P., Aftanas, M., Hasek, J., Sansom, W., Schludermann, E., Wilgosh, L., Winocur, G., Intellectual and perceptual changes during prolonged perceptual deprivation; low illumination and noise level. Percept. Motor Skills. 15:171, 1962.

A group of 42 Ss were placed individually in an isolation chamber under a condition of constant, unpatterned light and white noise for a period up to a week. Of this sample, 29 Ss endured isolation for 7 days. The remainder terminated the experiment sometime

102. (Cont). prior to the end of the third day. Two batteries of tests were administered. The first, measuring 12 different mental abilities, was administered before, during, and one day after isolation. The second, measuring 8 perceptual processes, was given before and immediately after isolation. A group of 40 ambulatory and a group of 40 recumbent control Ss were also given the same tests at the same time intervals.

Significant impairments were found on 8 of the 12 tests of the intellectual battery, viz., cancellation, dexterity, number facility, numerical reasoning, abstract reasoning, space relations, verbal fluency, and recognition. Suggestions of some impairment were found for recall and verbal reasoning. On digit span and rote learning a trend toward improvement was indicated. An analysis of the effect of short and week-long periods of perceptual deprivation revealed essentially the same picture. Little or no relationship seemed to exist between degree of intellectual impairment and duration of isolation. Some suggestions were present that adaptation to deprivation conditions may be possible. The results from the recumbent control group indicated that the factor of motility is important in numerical reasoning and possibly in space visualization and verbal fluency.

Significant impairments were found on 5 of the 8 perceptual tests, viz., visual and auditory vigilance, color discrimination and reversible figures. Ss were also less sensitive to pain. Depth perception, size constancy, and perception of lines were not affected. Hallucinatory-like experiences were found to be infrequent. The recumbent position did not affect performance on any of the perceptual tests.

A comparison of the results of the present study with those of an earlier one indicated that sensory and perceptual deprivation are not equivalent behaviorally.

103. Zubek, J. P., Wilgosh, L., Prolonged immobilization of the body; Changes in performance on the electroencephalogram. <u>Science 140</u>:306, 1963.

Subjects were immobilized for a week in a foam rubber padded box 7' x 28" x 18" by means of belts on trunk and legs, but were otherwise exposed to a normal varied sensory environment. They showed intellectual and perceptual impairment similar in many respects to that occurring after prolonged visual and auditory deprivation. A significant change in EEG was observed, with a decrease in occipital lobe frequencies.

104. Zuckerman, S., Perceptual isolation as a stress situation. A Review. Arch. Gen. Psych. 11:255, 1964.

This is a very comprehensive study of perceptual isolation and sensory deprivation, chiefly the latter. Amongst many others, author quotes work of Zubek et al., (Zubek, J. P., et al., Effect of severe immobilization of the body on intellectual and perceptual processes, Canad. J. Psychol. 17:118, 1963) who kept subjects severely immobilized, but in a normal and varied sensory environment. Controls were recumbent under similar conditions but not severely immobilized. A significantly greater percentage of experimental subjects reported concentration difficulties, thoughts jumbled, mind blank, unusual and peculiar thoughts, perseveration of ideas, concern over slow passage of time, anxiety, fear of losing control, worry, restlessness, irritability, anger, strange body sensations, changes in body image or position, and a variety of somatic complaints. Only 25% of immobilized group were willing to repeat experiments as against 75% of controls. Confinement became in effect a pain endurance study. Author's general conclusions were: endurance of isolation is lowest in water immersion, intermediate in respirator confinement and greatest in bed confinement. Subjects personal "sets" may be major factor in determining isolation endurance. Sets may account for sex differences. Social stimulation may facilitate or reduce endurance and fantasy in perceptual isolation depending on characteristics of the stimulation. Movement restriction does not reduce endurance unless it is so severe that it produces painful somatic discomfort. Conversely, exercise does not increase endurance. Type or somatic degree of visual and auditory restriction is less important in producing a verbal stress reaction than the general unchangeability of the sensory environment. Adaptation to isolation during repeated sessions is reflected in decreasing verbalization of effects but not seen in endurance or post-isolation measures of stress. Psychological disturbances in psychiatric patients may reduce endurance to isolation stress. Most subjects report difficulties in directed thinking and concentration. Negative emotional reactions, such as anxiety, predominate over positive emotional reactions and often lead to request for release. Isolation for periods of two hours or less does not produce physiological or biochemical indications of stress response. More extended periods of isolation may produce galvanic skin response changes and increased output of catecholamines. No increase in corticoids has been found. Progressive slowing of EEG frequencies and diminution of the alpha wave rhythm occurs over extended periods. Recovery of alpha wave rhythm after release is slow. Gross body movement increases as a function of time, and repeated sessions, and is a good predictor of endurance.

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